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Processing Refinery Wastewater by Coagulation and Flotation Following Biological Oxidation

Standard Oil Co (Indiana), Chicago, IL

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The refinery effluent treatment sequence consisting of API separators, aerated lagoon, chemical destabilization, and dissolved air flotation provides generally good effluent quality. Quality variability due to seasonal aerated lagoon performance, phenolics residuals above-pending goals, and minimal nitrification capacity, however, severely limits the applicability of this sequence to meet increasingly stringent quality goals.

Dissolved air flotation is a useful unit operation in any refinery end-of-pipe effluent treatment sequence. Extensive work on a heretofore ignored approach to optimization of this unit operation involving negating the mutual repulsion of negatively charged flotation bubbles and negatively charged suspended solids is reported. Extensive background on appropriate water chemistry, properties, and characteristics of chemicals used in destabilization of colloid systems, chemical antagonists in waste waters, principles involved in colloid destabilization, and chemical models proposing a mechanism for destabilizing negatively charged solids with negatively charged polyelectrolytes is presented.

Important design considerations for air flotation units are discussed, and guidelines for optimization of performance by proper chemical destabilization are presented.

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FOREWORD

The Environmental Protection Agency was established to coordinate administration of the major Federal programs designed to protect the quality of our environment.

An important part of the Agency's effort involves the search for information about environmental problems, management techniques and new technologies through which optimum use of the nation's land and water resources can be assured and the threat pollution poses to the welfare of the American people can be minimized.

As one of these facilities, the Robert S. Kerr Environmental Research Laboratory is responsible for the management of programs to: (a) investigate the nature, transport, fate and management of pollutants in groundwater; (b) develop and demonstrate methods for treating wastewaters with soil and other natural systems; (c) develop and demonstrate pollution control technologies for irrigation return flows; (d) develop and demonstrate pollution control technologies for animal production wastes; (e) develop and demonstrate technologies to prevent, control or abate pollution from the petroleum refining and petrochemical industries, and (f) develop and demonstrate technologies to manage pollution resulting from combinations of industrial wastewaters or industrial/municipal wastewaters.

This report contributes to the knowledge essential if the EPA is to meet the requirements of environmental laws that it establish and enforce pollution control standards which are reasonable, cost effective and provide adequate protection for the American public.

W. C. Galegar

W. C. Galegar
Director
Robert S. Kerr Environmental Research Laboratory

ABSTRACT

The refinery effluent treatment sequence consisting of API separators, aerated lagoon, chemical destabilization, and dissolved air flotation provides generally good effluent quality. Quality variability due to seasonal aerated lagoon performance, phenolics residuals above-pending goals, and minimal nitrification capacity, however, severely limits the applicability of this sequence to meet increasingly stringent quality goals.

Dissolved air flotation is a useful unit operation in any refinery end-of-pipe effluent treatment sequence. Extensive work on a heretofore ignored approach to optimization of this unit operation involving negating the mutual repulsion of negatively charged flotation bubbles and negatively charged suspended solids is reported. Extensive background on appropriate water chemistry, properties, and characteristics of chemicals used in destabilization of colloid systems, chemical antagonists in waste waters, principles involved in colloid destabilization, and electrical models proposing a mechanism for destabilizing negatively charged solids with negatively charged polyelectrolytes is presented.

Important design considerations for air flotation units are discussed, and guidelines for optimization of performance by proper chemical destabilization are presented.

This report is submitted in fulfillment of Project 12050-DML under the partial sponsorship of the Water Quality Office of The Environmental Protection Agency. The initial phase was completed as of October, 1972. Subsequent work, reported chiefly in the Addendum Section, is ongoing.

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ABBREVIATIONS

Organizations

APWA	American Public Works Association
ASCE	American Society of Civil Engineers
DMWS	Detroit Metropolitan Water Service
EPA	U.S. Environmental Protection Agency
MSDGC	Metropolitan Sanitary District of Greater Chicago
NPDES	National Pollution Discharge Elimination System
NSF	National Science Foundation
OWRR	Office of Water Resources Research
RD&D	Research, Development, and Demonstration Program (EPA)
USPHS	U.S. Public Health Service

Symbols

%	per cent
$	dollar
^oC	degree(s) Celsius (Centigrade)
$\sim$	approximately
$>$	greater than
$<$	less than
$\geq$	greater than or equal to
$\leq$	equal to or less than

¢	cents
/	per
ABS	acrylonitrile butadiene styrene
AFU	air flotation unit
API	American Petroleum Institute
avg	average
BFU	bioflotation unit
BOD_5	biochemical oxygen demand (5-day)
cf or cu ft	cubic foot (feet)
cfs	cubic feet per second
cf/lb	cubic feet per pound
cm	centimeter(s)
cm/hr	centimeter(s) per hour
cm/yr	centimeter(s) per year
COD	chemical oxygen demand
CPVC	chlorinated polyvinylchloride
cu m	cubic meter(s)
cu m/day	cubic meter(s) per day
cu m/min/day	cubic meter(s) per minute per day
cu m/min/ha	cubic meter(s) per minute per hectare
cu m/min/100 l	cubic meter(s) per minute per 100 liters
cu m/sec	cubic meter(s) per second
cy	cubic yard

degree C	degree(s) Celsius (Centigrade)
degree F	degree(s) Fahrenheit
DO	dissolved oxygen
DWF	dry-weather flow
eff.	effluent
ENR	Engineering News-Record (index)
F/M	food-to-microorganism ratio
fpm	feet per minute
fps	feet per second
FRP	glass fiber-reinforced plastic
ft	foot (feet)
g	gram(s)
gal.	gallon(s)
gal./inch diameter/ mile/day	gallons per inch diameter per mile per day
gpd/sq ft	gallon(s) per day per square foot
gpm/sq ft	gallon(s) per minute per square foot
ha	hectare
hr/yr	hour(s) per year
HST	heat shrinkable tubing
in.	inch(es)
in./hr	inch(es) per hour

in./yr	inch(es) per year
JTU	Jackson turbidity unit
kg	kilogram(s)
kg/sq cm	kilograms per square centimeter
kl	kiloliter(s)
km	kilometer(s)
kwh	kilowatt hour(s)
lb	pound(s)
lb/day	pounds per day
lb/mil gal.	pounds per million gallons
lb/min	pound(s) per minute
lb/yr	pounds per year
l/day/ha	liter(s) per day per hectare
l/kg	liter(s) per kilogram
l/min/sq m	liter(s) per minute per square meter
l/sec	liter(s) per second
l/sec/sq m	liter(s) per second per square meter
m	meter(s)
max	maximum
mg	milligram(s)
mgad	million gallons per acre per day

mgd	million gallons per day
mg/l	milligrams per liter
mil gal.	million gallons
min	minute(s)
min	minimum
Ml	megaliter(s)
ml	milliliter(s)
MLSS	mixed liquor suspended solids
ml/l	milliliter(s) per liter
mm	millimeter(s)
MPN	most probable number
m/sec	meter(s) per second
N	nitrogen
NA	not available
N/A	not applicable
P	phosphorus
pcf	pounds per cubic foot
ppm	parts per million
psf	pounds per square foot
psi	pounds per square inch
PVC	polyvinylchloride
PVDC	polyvinyldichloride

rpm	revolutions per minute
RRL	Road Research Laboratory
scfm	standard cubic feet per minute
sq cm	square centimeter(s)
sq ft	square foot (feet)
sq ft/mgd	square feet per million gallons per day
sq in.	square inch(es)
sq km	square kilometer(s)
sq mi	square mile(s)
sq m/cu m/sec	square meter per cubic meter per second
SS	suspended solids
STP	sewage treatment plant
SWMM	Storm Water Management Model
TOC	total organic carbon
TOD	total oxygen demand
TON	threshold odor number
TSS	total suspended solids
TVS	total volatile solids
VS	volatile solids
VSS	volatile suspended solids
yr	year(s)

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Mr. A. L. Conn of Amoco Research made the arrangements for the Research and Development grant.

Mr. R. C. Mallatt of Standard Oil Company was Project Manager.

The evaluation studies of the Bio Flotation Pond and Air Flotation Unit were a team effort carried out by the Technical Service Department at the Whiting Refinery.

The director of the project evaluation was Mr. V. G. Skogan. Engineers assisting in the evaluation were Messrs. R. L. Campion, A. E. Franzen, J. F. Grutsch, R. E. Huffman, D. C. Kloeckner, P. W. Rosten, and R. A. Sokol.

The centrifuge studies were performed by Dr. J. L. Carter of the Research Department of the American Oil Company.

The Operating Superintendent, Mr. G. C. Flood, arranged for operator assistance and craft services very necessary to completing many of the investigations.

Messrs. J. F. Grutsch and D. C. Kloeckner developed the appropriate water chemistry background, conducted the laboratory studies, ran the plant tests, and prepared the Addendum Section.

The project was made possible by the Water Quality Office of the Environmental Protection Agency. Mr. Stephen Poloncsik, Research and Development Program Representative, and Mr. Clifford Risley, Jr., EPA Project Officer, provided guidance which greatly assisted the completion of these studies.

The support of all the above is gratefully acknowledged.

SECTION 1

INTRODUCTION

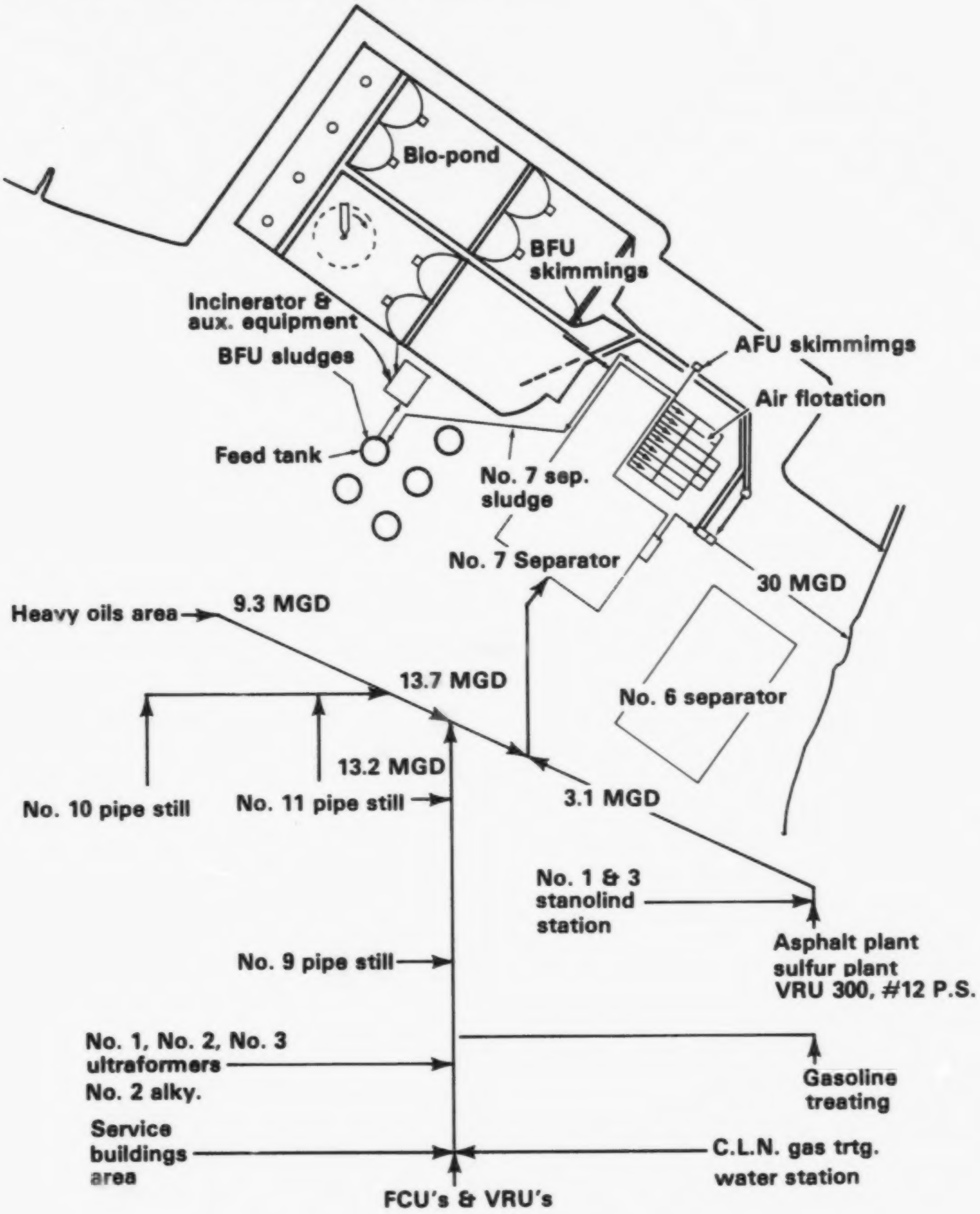
Amoco Oil Company has a large refinery on the southern shore of Lake Michigan in Whiting, Indiana. It is a Class D refinery, lube subcategory, as classified under the EPA effluent Guidelines in the Federal Register of May 9, 1974. It produces a diversified array of products, including liquid petroleum gases, gasolines, turbine fuels, home heating oils, residual fuels, paving and industrial asphalts, petroleum coke, a complete line of automotive and industrial lubricants and greases, and refined waxes. The data in this report were obtained in the period September, 1970, to April, 1972, except for data included in the Addendum, which was developed subsequently through 1978. During the period September-December, 1970, the crude run was 285,700 B/D with no downtime. During 1971, the crude run was 246,700 B/D, with the crude units operating 95.3 per cent of the time. During January-April, 1972, the crude run was 269,100 B/D with no downtime. Whiting's charges of 67 per cent midcontinent plus canadian low sulfur (1 per cent) crudes and 33 per cent midcontinent high sulfur (2-3 per cent) crudes.

Because of the complexity and size of the refinery, a significant amount of process water which has been in contact with oil and chemicals is generated (Figure 1). This waste water stream requires extensive treatment before discharge into the receiving body, which is Lake Michigan. Before 1978, three stages of treatment were in effect: primary treatment in API-type separators, secondary treatment in a bioflotation lagoon, and a final stage of chemical coagulation/flocculation and air flotation. The final stage proved to be an effective method for removal of contaminants.

Through the years, the Amoco Oil Company has recognized the continuing need to improve the quality of process water effluent and has maintained a development program for making these im-

Figure 1

Process water system


Bio-pond
BFU skimmings
Incinerator & aux. equipment
BFU sludges
AFU skimmimgs
Air flotation
Feed tank
No. 7 sep. sludge
No. 7 Separator
30 MGD
Heavy oils area
9.3 MGD
13.7 MGD
No. 6 separator
13.2 MGD
No. 10 pipe still
No. 11 pipe still
3.1 MGD
No. 1 & 3 stanolind station
Asphalt plant sulfur plant VRU 300, #12 P.S.
No. 9 pipe still
No. 1, No. 2, No. 3 ultraformers No. 2 alky.
Gasoline treating
Service buildings area
C.L.N. gas trtg. water station
FCU's & VRU's

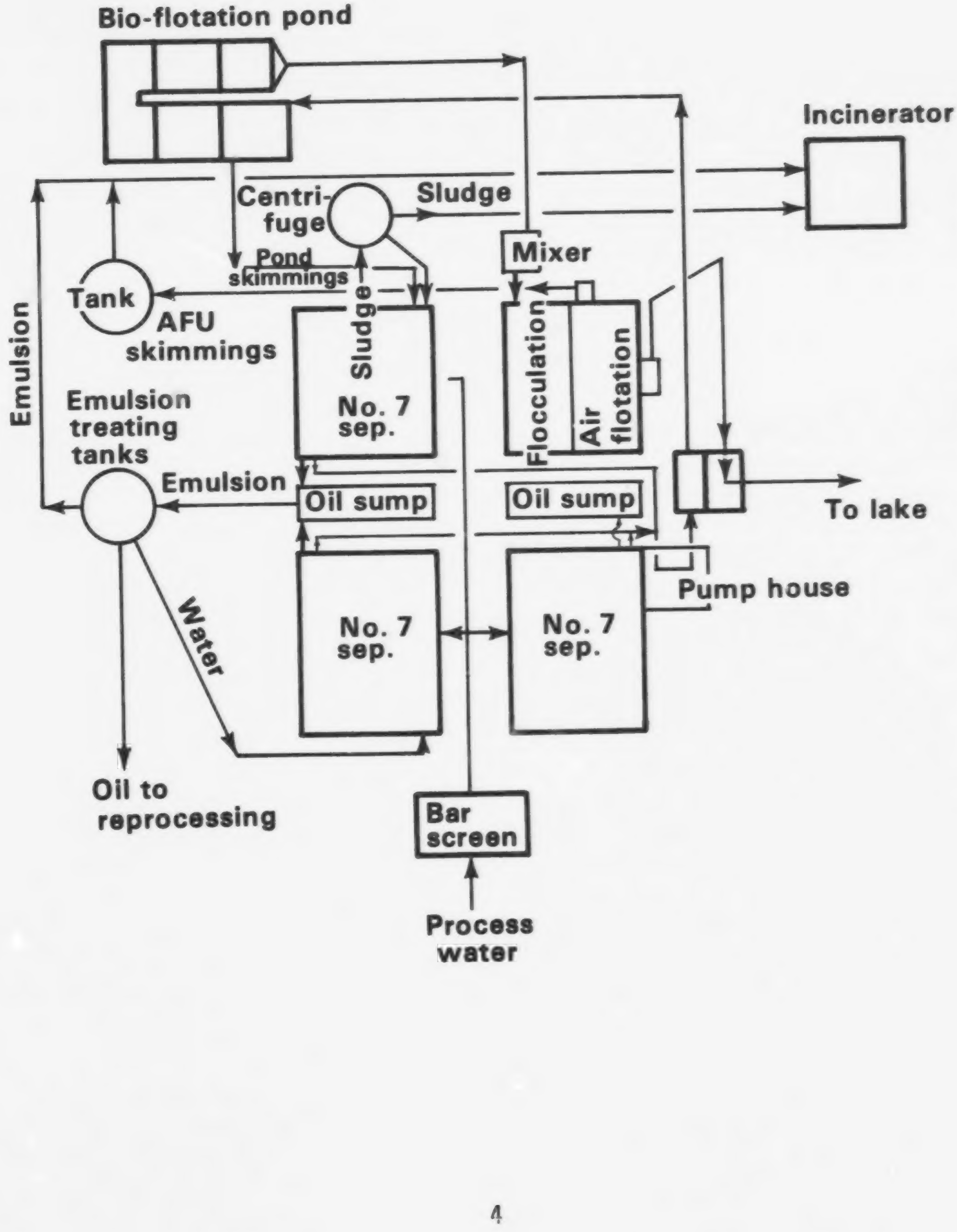
provements. The company had developed an effective second-stage treatment called the Bioflotation Process[1] which was installed at the Whiting refinery in 1960. This process uses a series of lagoons where biological oxidation, sedimentation, bioflocculation, and air flotation of bioflocculated, suspended solids and occluded oil occur in a series of four aerated lagoons. Air flotation of bioflocculated solids and oil is achieved by microbubbles generated by the Passavant delta brush aerators used at the inlet of each of the four aerated lagoons (Figure 2).

Recognizing the need for further improvement of effluent water quality, the company carried out extensive pilot plant work to select a process that could be used effectively with the secondary bioflotation process. Chemical treatment with alum and polyelectrolyte was first selected to coagulate the residual contaminants. Phase separation either by dissolved air flotation or by mixed media filtration was then investigated in pilot plant equipment. Air flotation was finally selected because it avoided reprocessing of large volumes of backwash that would result from filtration and because existing space in surplus boxes in the API separator could be utilized for the coagulation and air flotation sections.

From the pilot plant work, a decision was made to use chemical coagulation plus air flotation as the tertiary treatment following the secondary bioflotation treatment. With this sequence, the effluent had a better appearance. Also, phosphates are effectively removed in the final step. Previously, other installations in the petroleum industry have used chemical coagulation plus air flotation as a stage of treatment after primary gravity settling and before biooxidation. Because the processing sequence at Whiting was different, the American Oil Company, predecessor of Amoco Oil Company, made application to the Federal Water Pollution Control Administration, a predecessor of the Environmental Protection Agency, for a Research and Development grant as provided in the Clean Water Restoration Act of 1966 to demonstrate essentially complete cleanup of refinery process water by chemical treatment and air flotation following conditioning by the bioflotation process. The American Oil Company accepted a Research and Development grant from the Water Quality Office of the Environmental Protection Agency in 1969, Project 12050-DML, of $336,535 or 19 per cent of the actual cost eligible for federal participation, whichever is less.

Figure 2

Lakefront facilities



Bio-flotation pond
Incinerator
Centri-fuge
Sludge
Pond skimmings
Mixer
Tank
Sludge
AFU skimmings
Emulsion
No. 7 sep.
Flocculation
Air flotation
Emulsion treating tanks
Emulsion
Oil sump
Oil sump
To lake
Pump house
Water
No. 7 sep.
No. 7 sep.
Oil to reprocessing
Bar screen
Process water

The project objectives were:

1. to demonstrate the advantages of installing chemical coagulation and air flotation following an aerated lagoon to provide refinery effluent quality consistent with standards for tertiary treatment;

2. to establish what operating flexibilities exist in such combination processing and the costs associated therewith;

3. to evaluate a number of unique design features, including a unique and low-cost method for preventing sludge deposition in an aerated lagoon;

4. to demonstrate a novel application of rotary drum skimmers for the recovery of floated material from the aerated lagoon; and

5. to make a comparative study of alternate design features for air flotation.

The dissolved air flotation facilities were installed in surplus API separator boxes. Through continuing efforts to reduce the volume of process water, it became possible to make seven of the 34 API separator sections available for modification into a dissolved air flotation unit.

This facility was a project of the Manufacturing department of the American Oil Company. Responsibility for the project was divided into two phases:

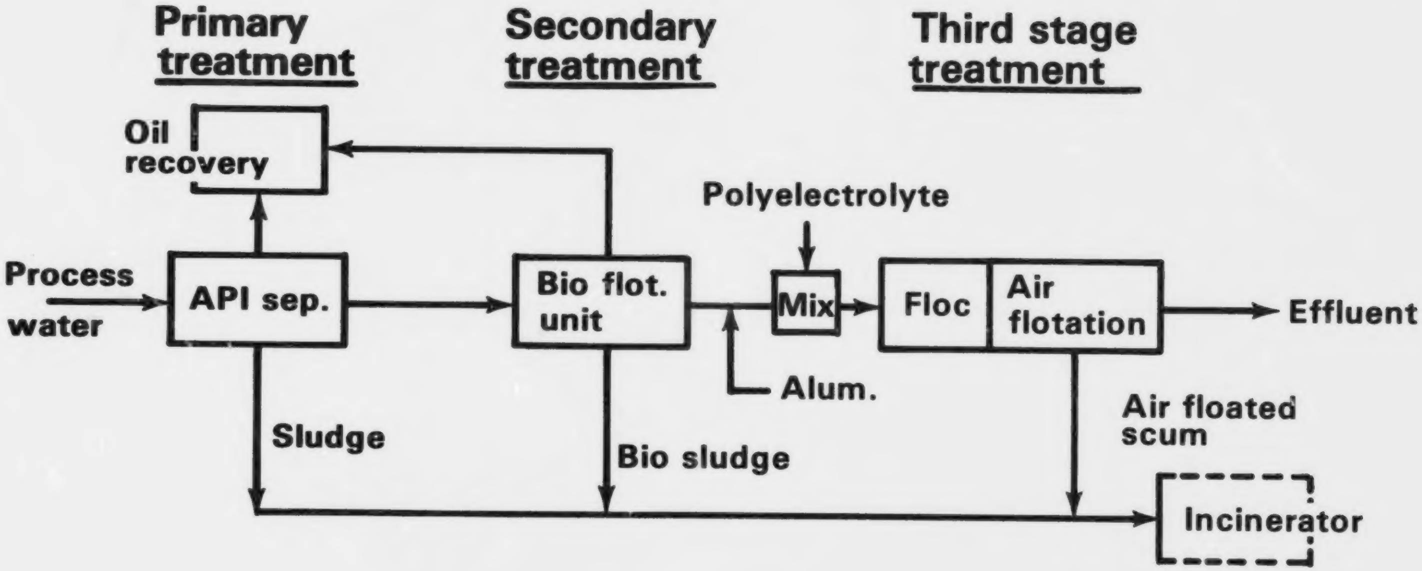
Phase I - Engineering and construction were the responsibility of the Planning and Engineering department of the American Oil Company at Whiting, Indiana;

Phase II - Postconstruction studies and reports were the responsibility of the Technical Service personnel at the Whiting refinery.

The process flow in use is shown in Figure 3. Primary and secondary treatments remove oil which is sent to recovery. All three stages remove sludges which are disposed of in a fluidized

Figure 3

Waste water treatment facilities


Primary treatment
Secondary treatment
Third stage treatment
Oil recovery
Process water
API sep.
Bio flot. unit
Polyelectrolyte
Mix
Alum.
Floc
Air flotation
Effluent
Sludge
Bio sludge
Air floated scum
Incinerator

bed incinerator. The secondary bioflotation process aerated lagoon reduces biochemical oxygen demand (BOD), total oxygen demand (TOD), threshold odor number (TON), and phenolics as well as oil content. The third stage of treatment makes further substantial reductions in all of the above parameters and also in turbidity and total suspended solids, reducing them to levels associated with tertiary treatment goals and provides an effluent containing dissolved oxygen.

The goals believed achievable with the third stage of treatment (chemical coagulation and dissolved air flotation) are effluent concentrations of 20 mg/l of BOD, 120 mg/l of TOD, 0.2 mg/l of phenolics, 10 mg/l of APHA oil, 10 mg/l of TSS, 0.1 mg/l of phosphorus, and 10 Jackson Turbidity Units (JTU). It is anticipated that TON will be reduced 80 per cent.

These goals met the objectives of the Indiana State Board of Health at the inception of the project.

ADDENDUM STUDIES

After completion of the required plant studies, it became apparent that more stringent effluent quality goals would have to be addressed. In this, and alternative end-of-pipe treatment sequences, the dissolved air flotation unit operation was a key element in the optimization of the treatment sequence. Accordingly, studies were continued which focused on determining the key parameters for optimizing the air flotation unit operation. These studies were highly successful and are reported in the Addendum, Section XIV.

This report, therefore, is bifurcated. The initial part of the report concerns data obtained during the period September, 1970, to April, 1972. Continuing studies on water chemistry and the availability of improved chemicals have provided guidelines for optimizing the performance of air flotation units. Since this unit operation will continue to be vital to the successful optimization of industrial end-of-pipe waste water treatment sequences, the in-depth technology base developed is described in the Addendum.

SECTION HIGHLIGHTS

Section 4:	discusses the theory of coagulation and dissolved air flotation.
Section 5:	compares the pilot plant and full-scale unit design.
Section 6:	discusses the initial operation and the many modifications made to improve effluent quality.
Section 7:	reports the tests run to determine the optimum process variables.
Section 8:	compares the initial pilot plants results to the full-scale unit and subsequent pilot plant testing in order to explain the differences.
Section 9:	evaluates the performance of the chemical coagulation--air flotation unit in terms of percentage of contaminants removed.
Section 10:	describes our patented bioflotation process and the orbiting aerator and roller drum skimmers which were investigated for this report.
Section 11:	reports on the effect of the orbiting aerator on TSS and the bottom sludge level. It also reports on the removal of surface oil by the roller drum skimmers and the overall effectiveness of the biopond.
Section 12:	discusses mechanical problems with the orbiting aerator, the roller skimmers, and the pumps.
Section 13:	presents a summary of operating and maintenance costs.
Section 14:	presents addendum studies wherein the key to optimizing the phase separation efficiency of the air flotation process is recognition that an intrinsic property of air bubbles and solids in the presence of water is a negative electrical surface charge.

The magnitude of this charge must be controlled if the colloidal and supracolloidal solids are to be efficiently captured and removed. This section discusses the nature and origin of the electric surface charge, chemical destabilization mechanisms, chemicals used for destabilization, their chemical and electrical properties, chemical and biological destabilization models, and destabilization recommendations for optimizing air flotation unit performance.

SECTION 2

CONCLUSIONS

The combination of the bioflotation and dissolved air flotation processes has been demonstrated to be an effective means for treatment of refinery waste water at an operating cost of 7.5 cents per 1,000 gallons when the objectives are low residual APHA oil content, suspended solids, and phosphorus (phosphate). As shown in the summary below, the effluent quality from the full-scale commercial equipment does not attain the quality from pilot scale equipment.

Quality Parameter	AFU Effluent (May, 1971)	Pilot Plant
APHA Oil Content, mg/l	3	1
BOD_5, mg/l	15	15
TSS, mg/l	13	8

This difference in performance is ascribed to the difference between the inherent hydraulic characteristics of the two air flotation units. The pilot unit operated in the near-streamline-flow region at a relatively low overflow rate. The air flotation unit operated in the turbulent flow region at a relatively high overflow rate. Studies revealed that the deleterious effects of hydraulic turbulence is overcome by a substantial increase in the air to oil plus solids ratio. Pilot unit performance was obtained when flow was reduced 50-60 per cent and recycle rate increased from 25 per cent to 60-80 per cent.

Later studies revealed that minor hydraulic shortcomings are overcome by consistently chemically pretreating to reduce the high negative zeta potential of the influent to at least -3mV or less.

This provides consistent and optimum phase removal by the dissolved air flotation process when the destabilized solids are flocculated. The performance goal for phase removal by the plant air flotation unit is achievable using various approaches to chemical destabilization:

> A three-chemical destabilization system in which a fixed amount of 30 mg/l alum is added followed by enough dimethylamine/epichlorohydrin-type cationic polyelectrolyte to reduce the zeta potential of the alum-treated solids to -3mV or more positive values. Then, flocculating with 0.2 to 0.4 mg/l active ingredient anionic polyelectrolyte.
>
> A two-chemical destabilization system in which a fixed amount of 10-20 mg/l alum is added and enough high molecular weight quaternized polyacrylamide-type cationic to reduce the zeta potential to at least -3mV. This particular cationic is selected because of its effective charge neutralizing and flocculating capability; thus no anionic is used.
>
> A one-chemical destabilization system in which enough high molecular weight quaternized polyacrylamide-type cationic polyelectrolyte is added to bring the zeta potential to at least -3mV.

The use of alum and low molecular weight cationic polyelectrolyte is effective for charge neutralization and requires an anionic polyelectrolyte for flocculation of destabilized solids suitable for removal by air flotation. In the two- and three-chemical systems, alum is frequently found to more rapidly and effectively reduce residual turbidity, and exhibit synergistic destabilization activity with certain organic cationic polyelectrolytes. The high molecular weight quaternized polyacrylamide-based cationics exhibit both exceptional charge neutralization and exceptional flocculating ability. These newer-type cationics are, therefore, found to be especially effective.

Satisfactory effluent water quality cannot be achieved unless the impact of components antagonistic to the destabilization chemicals used is recognized and compensated for. Zeta potential measurements are especially useful in this regard. In the initial studies, sulfonates produced by acid-treating of petroleum distillates were thought to be most troublesome. In the subsequent studies, these manufacturing facilities were abandoned, but phenolics, salinity, pH, and particularly sulfides were found to be antagonistic to destabilizing chemicals, and their antagonistic effects must be compensated for.

Operation of the bioflotation unit is benefited by the roller skimmers removing oil and possibly by the orbiting aerator increasing aeration. The orbiting aerator probably inhibits the use of sludge in the aerated lagoon, but the original design required an abnormal amount of maintenance to keep it in operation. The roller skimmers recover floated material which accumulates on the surface, but, initially, the operating factor of these units was low. Since substituting a simple cellar-type sump pump for the screw-type positive displacement pump, operation has been satisfactory. These units still cease to function at temperatures below + 10° F.

At the inception of the project, tertiary treatment goals were not in focus by the various agencies involved. One immediate goal of the State of Indiana was phosphate removal and the use of alum in the final step of this sequence studied provided for that. The treatment of aerated lagoon effluents for phase removal also had a dramatic visual, that is aesthetic, effect, and progress was made that could be seen. Further, contamination associated with colloids and suspended matter removed was very substantial, but as longer-term tertiary treatment goals came into focus, and we continued our research effort, it became apparent that the subject treatment sequence was not the best approach to meet consistently more restrictive effluent water quality objectives:

Comparison of Effluent Quality Goals

Parameter*	Target	Obtained	Tertiary
Oil (APHA)	10	4.4	2
Phenolics	0.2	.174	0.1
BOD	20	20.2	10
COD	-	40	60
TSS	10	13.1	10
TPO$_4$	0.2	0.08	
TON$^+$	80	77	-

*All mg/l except TON

$^+$% Reduction

Variable seasonal performance of the aerated lagoon, the potential of restrictive ammonia goals, and the impossibility of achieving phenolics goals by the aerated lagoon approach led to abandonment of this sequence as a means for the refinery to meet 1977 BPCTCA goals. The aerated lagoons at Amoco's Wood River and Yorktown refineries were abandoned, and the use of an alternate sequence at Texas City refinery was a major result of this study.

SECTION 3

RECOMMENDATIONS

The refinery effluent treatment sequence consisting of API separators, aerated lagoon, chemical destabilization, and dissolved air flotation provides generally good effluent quality but has serious limitations because of quality variability due to seasonal effects, residual phenolics above pending goals, and little ammonia removal capability. This sequence has limited applicability, therefore, to meet increasingly stringent quality goals.

Where aerated lagoons are viable, two equipment items potentially valuable were studied: orbiting aerators and roller skimmers.

The orbiting aerator was not adequately designed for orbiting service. This type of service puts unusual strains on the shafts and couplings. A properly designed unit should function as reliably as most rotating equipment. Our unit has not been reliable enough to be recommended.

Much of the poor performance of the roller skimmers is due to malfunctioning sump pumps and subfreezing temperatures. The cellar-type sump pump gives more reliable performance than the original equipment screw-type pump. Cold weather operations are still a problem, so a recommendation for use cannot be made.

Dissolved air flotation is a useful unit operation in any refinery end-of-pipe treatment sequence. Experimental projects and operating experience indicated areas where overall performance is improved by proper design considerations. Thus, the objective and limitations of the unit in technical terms should not be ignored.

1. A proper place to start design considerations of the air flotation process is a definition that recognizes the principle limitation of the process; it will not efficiently achieve the phase separation of negatively charged colloidal solids. The proper definition should spell out the process characteristics more carefully than done heretofore:

Dissolved air flotation is defined as clarification of a suspension of flocculated material by contact with minute bubbles that attach to the bubbles constituting the suspension, causing the suspension to be separated from the clarified water by flotation.

2. The recommended definition puts emphasis on the fact that the material being separated should not be colloidal with its inherent, high, repulsive, negative zeta potential required to maintain the colloidal state, but a flocculated suspension. A flocculated suspension requirement determines the design considerations of the air flotation unit:

   a. It shall consist of three elements: chemical mixing, flocculation, and flotation zones.

   b. Dissolved air flotation designs using total, or partial, feed pressurization are not appropriate, because any flocculation of the destabilized suspension achieved by pretreatment is destroyed by the pressure drops in the pressurization facilities.

   c. Recycle air pressurization designs are, therefore, preferred.

   d. Flotation air bubbles have a negative electric surface charge that inherently repels dispersed phase materials negatively charged; therefore, the pretreatment goal for optimizing phase removal is to reduce the zeta potential of solids in the pretreatment system to at least -3mV or more positive values. An added requirement is to select a chemical destabilization system which results in formation of tough flocculated aggregates that do not disaggregate in the recycle air contact chamber.

   e. Many waste water contaminants such as phenolics, hydroxide ion concentration, salinity, and sulfides react antagonistically with many of the chemicals used for destabilization. Antagonists in the waste water must be compensated for in the chemical treatment system.

3. Experimental projects and operating experience have indicated areas where overall performance could be improved by a different design. In designing a new system, attention should be given to the following design factors:

   a. Hydraulic Effects

      The turbulent flow conditions that are a natural consequence of a large, cross-sectional area will have detrimental effects on the quality of the effluent. This can be overcome by designing for an overflow rate of 1.8 gpm/ft^2 or less and 60-80 per cent recycle at 50 psig saturation pressure.

   b. Gross Air Release

      (1) Control the premature release of flotation air by minimizing the residence time in the recycle line downstream of the pressure-reducing valve.

      (2) Avoid bubbling in front of the beach by installing vents to bleed off trapped flotation air.

   c. Polyelectrolyte Addition

      Multipoint addition facilities for polyelectrolyte are not necessary; the polyelectrolyte may be added at a single point at the inlet to the flocculator or directly into the flash-mix zone less than 30 seconds downstream of the alum addition point. Progressing cavity (screw) type pumps are preferred for handling organic polyelectrolytes.

   d. Alum Addition

      The diaphragm-type pump is not recommended for pumping 48 per cent aluminum sulfate solution because a precipitate blocks the orifices in the diaphragm head. A gravity feed system with a magnetic flow controller is preferred.

   e. Scum Removal

(1) Provide a combination of skimmer speed and dry-beach length that will allow about 60 seconds to drain gross-entrained water from the scum. This can have a substantial effect on the water content of the scum. Provide a wide range of skimmer speeds with ability to go down to 1 fpm.

(2) Provide a spare pump to transfer scum from the scum pit to the disposal plant.

(3) Provide a blade long enough to cut entirely through the scum layer with enough freeboard above the scum to permit a thick scum blanket to be properly skimmed.

4. Chemically pretreat feed to an air flotation unit using a target zeta potential of -3mV or more positive for colloid destabilization.

SECTION 4

COAGULATION, FLOCCULATION, AND FLOTATION THEORY

COAGULATION THEORY

The following paragraphs discussing coagulation outline the applied technology prevailing at the time of the grant: 1972 and prior. Subsequent studies prior to the final draft (July, 1978) demonstrated that addressing the water chemistry was the key to optimizing the phase separation performance of the air flotation process in the most cost-effective manner. This involved recognizing that an intrinsic property of solids and air bubbles in the presence of water is a negative electric surface charge. Maximizing solids capture and phase separation by air flotation requires that these coulombic, repulsive forces be controlled by controlling the physicochemical properties of the dispersed phase. Electrical properties of water-borne suspended matter, colloid destabilization mechanisms, chemical properties of destabilization chemicals, and a procedure to determine optimal chemical treatment preparatory to air flotation are described in detail in Section XIV, Addendum.

The oil and solids in the effluent from the bioflotation unit are colloidally dispersed. These colloids can be classified broadly as hydrophilic and hydrophobic. Hydrophilic colloids attract water to their surfaces which engenders stability by preventing particle-to-particle contact. Hydrophobic colloids achieve stability according to the classical double-layer theory advanced by Helmholtz. The colloids acquire an electrical charge by ionization or adsorption of ions. This charge is usually negative for particles in waste water.

Electric double-layer theory considers the distribution of counter-ions and co-ions in the region of a charged surface, and the magnitude of the electric potentials occurring in this region. The electric double layer consists of two regions: an inner region which may include adsorbed ions, and a diffuse region in which ions are distributed according to electrical forces and thermal motion. Increasing the thickness of the double layer and the electrical potential results in increasing particle dispersion. Since these properties are dependent upon the concentration and valence of the ions in solution, the stability of the suspension can be reduced by adding appropriate ions.

Coagulation is defined as the destabilization of a colloidal dispersion by reducing the electrostatic and interionic forces tending to keep the particles peptized. In waste water treatment, the destabilization is accomplished by addition of an appropriate coagulant chemical and contact with the particles.

Flocculation, it follows, is defined as the growth in particle size achieved by gentle mixing which provides conditions for particle-to-particle contact, bridging, adsorption, and physical enmeshment.

The processes of coagulation and flocculation are affected by temperature, pH, alkalinity, salinity, the amount and kinds of solids, and the chemical properties of the coagulants and flocculants used. Upon completion of flocculation, the floc containing impurities is in suspension. Phase separation by air flotation requires that the flocculated particles be strong and resist the dispersive forces encountered when contacted by the recycle stream containing flotation air if maximum solids capture is desired. This subject is developed further in the Addendum.

Reactions of Primary Coagulants

Alum, $Al_2(SO_4)_3 \cdot 14H_20$; sodium aluminate, $NaAl0_2$; ferrous sulphate (copperas), $FeSO_4$; ferric chloride, $FeCl_3$ are some of the primary coagulants used. Originally, the metal ions were thought to be the effective coagulating agents, but it is now known that the hydrolysis products of the metal ions are the coagulating agents. The following description of the reaction of aluminum is greatly simplified.

Alum is the most widely used coagulant. Aluminum hydroxide can be formed from the reaction of commercial alum and the naturally occurring bicarbonate alkalinity of the water:

$$Al_2(SO_4)_3 \cdot 14H_2O + 6HCO_3^- \longleftrightarrow 2Al(OH)_3 + 3SO_4^= + 6CO_2 + 14H_2O$$

Alum hydrolyzes very acidically (a 1 per cent solution has a pH of 3.5) and because of the amphoteric nature of aluminum, is sometimes used in conjunction with lime when high alum dosages exceed the buffering capacity of the water.

Sodium aluminate is another aluminum salt from which aluminum hydroxide can be formed:

$$NaAlO_2 + HCO_3^- + H_2O \rightleftharpoons Al(OH)_3 + CO_3^= + Na^+$$

There appears to be no difference in the coagulating efficiency of equal amounts of aluminum hydroxide formed from either salt at equivalent final pH. (Alum contains 9.1 per cent aluminum by weight and sodium aluminate 34 per cent.) A combination of the two salts can be used to give precise pH control in unbuffered waters:

$$Al_2(SO_4)_3 \cdot 14H_2O + 6NaAlO_2 \rightleftharpoons 8Al(OH)_3 + 2H_2O$$

The reactions of iron salts are very similar to those of aluminum salts. Lime is usually added to produce a floc and with aeration, convert Fe^{2+} to Fe^{3+}, which minimizes soluble compounds of iron.

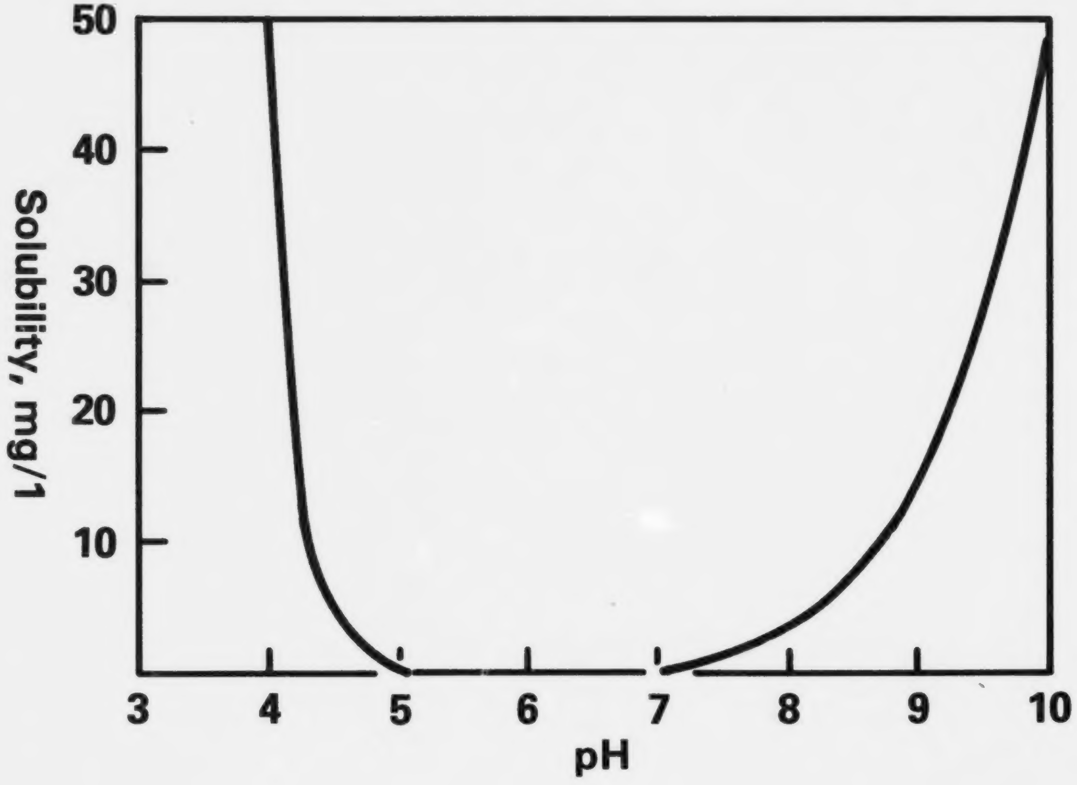
Coagulation and pH

There is at least one pH range in any given water in which good flocculation occurs in a given time with the minimum dose of coagulant.[2] Generally, the warmer the water, the more rapid the coagulation. Another generalization is that the optimum pH range for the coagulation of soft water with alum is usually within the acid range and may be as low as 5 pH. This is to be expected because at a pH of about 7.2 or less, the alum floc has a positive charge which can neutralize and thereby destabilize the negatively charged contaminant particles.[3] Further, the aluminum hydroxide is amphoteric and can act as an acid or base. The solubility curve is shown in Figure 4.

Maximum insolubility is about in the 5-6.5 pH range, the same range optimum removal of negative colloids typically occurs. The solubility curve for $Al(OH)_3$ trends upward at pH levels of 7 to 9 because of its amphoteric character and tends to form aluminate ion at high pH values.

Figure 4

Solubility curve for aluminum hydroxide from Sawyer, Chemistry for Sanitary Engineers, 1960



Polyelectrolyte Aids

In recent years, new chemical products have been developed to provide more versatile and effective coagulating and flocculating action. They are typically described as "synthetic water soluble organic polymers of high molecular weight." Their molecular weights may reach 10,000,000 or more. Amide, amine, carboxylic, and other polar groups may be distributed along the molecule to give it nonionic, cationic, or anionic properties. Coagulation/flocculation is achieved by adsorption of these long-chain polymers to suspended solids forming strong bonds between the polymer and the solid. After one end of the long molecule is adsorbed by a particle, the rest of the molecule is still free in the suspension to be adsorbed on other particles. With the many molecules in solution, this action quickly results in agglomeration and flocculation of the particles in suspension, which toughens the floc, thereby aiding flotation. Flocculating aids may be used singly, in combination, or in conjunction with primary coagulants. Polyelectrolytes are discussed in detail in Section XIV, Addendum.

DISSOLVED AIR FLOTATION

A study of dissolved air flotation requires an understanding of the physical properties of the three phases involved and how they interact with each other. The three phases include the flotation air, the floatable solids, and the water.

Air has a limited solubility in water, about 0.25 ft^3/100 gals. at 65° F and atmospheric pressure, and decreases with increasing temperature. The solubility of air in water follows Henry's law over a wide pressure range. Thus, by simply pressuring air into the water, flotation air becomes available on depressuring.

Air is slow to go into solution, and industrial installations will seldom approach saturation conditions. In addition, solubility of air in industrial waste water may be less than in clean water. The designed residence time allowed for saturation is usually limited by practical vessel sizes and fabrication costs. Saturation values of 50 per cent to 90 per cent have been reported.[4] The quantity of flotation air released in an operating situation when the pressure is reduced to atmospheric can be estimated from the following equation:

$$a = s\left[(fP/14.7) - 1\right]$$

where a = volume of air released per volume water

s = solubility of air in water, volume per volume

f = fraction of saturation attained

p = absolute pressure, psi

For example, at 85° F, the solubility of air in water at atmospheric pressure is 0.225 $ft^3/100$ gallons. If the water is 75 per cent saturated at 50 psig, the following volume of air will be released at atmospheric pressure:

$$a = 0.225\left[(.75 \times 64.7/14.7) - 1\right] = 0.52\ ft^3/100\ gals.$$

The application of chemical coagulation followed by dissolved air flotation as a means of phase separation in waste water is not unique. An explanation of the theory of air flotation and chemical coagulation will be helpful in understanding the operation of an air flotation unit.

When the pressure is reduced, the dissolved air precipitates as finely divided bubbles ranging in size from 30 to 120 microns with most of them in the 60-100 micron range and ready for attachment to the dispersed solids. According to Vrablik,[5] the air can become attached three different ways:

1. By adhesion of an air bubble to a particle either by collision or as condensation sites as the air precipitates out of solution.

2. By entrapment of the air bubble in the irregularities of flocculated particles.

3. By absorption of the air bubble in the floc structure as the floc is formed.

Provided the particles are large enough to be unaffected by Brownian movement and electrostatic forces, and the flotation zone is relatively free from turbulence, the particles tend to behave in accordance with Stokes' equation:

$$V_t = (dw-da)gD^2/18u$$

where V_t = terminal velocity of air-solid agglomerate, cm/sec

dw = density of water, g/cc

da = density of air-solids agglomerate, g/cc

D = diameter of air-solids agglomerate, cm

u = absolute viscosity of water, poises (gm/sec cm)

g = gravity constant, cm/sec^2

For the air flotation process to work, the value of the term (dw-da) must be greater than zero. The rate of rise varies directly with the square of the diameter of the air-solid agglomerate and with its density. Density can be changed only by making more flotation air adhere to the particles.

Diameter can be easily increased by substantial amounts by means of chemical coagulation and flocculation. In addition, the flocculated particles will trap and retain more air than individual particles.

There are three types of dissolved air flotation units in use: total, partial, or recycle pressurization. Total pressurization involves pressurizing the entire feed stream through an air saturation tank, and the pressure is released immediately adjacent to the flotation chamber. In partial pressurization, a portion of the feed stream is pressurized through an air saturation tank and is depressured into the main feed stream as it enters the flotation chamber. In recycle pressurization, a portion of the effluent from the flotation unit is pressurized through an air saturation tank and is depressured into the feed stream as it enters the flotation chamber.

An inherent advantage of the recycle design is that dispersed matter can be preflocculated and separated. In total or partial pressurization systems, the pumping and depressurization steps disperse flocculated solids thereby lowering their capture efficiency.

SECTION 5

DESIGN AND CONSTRUCTION

The Planning and Engineering Department of the Amoco Oil Company had the responsibility for the process and mechanical modifications necessary to convert seven two-stage API separator boxes to seven flocculator-air flotation units. Design parameters had been determined by extensive testing on a commercial, dissolved air flotation unit of smaller size. Typical operating parameters for the pilot unit are listed in Table 1 with the design operating parameters for the seven full-scale units:

Table 1. OPERATING PARAMETERS FOR AIR FLOTATION

Parameter	Pilot Unit	Full-Scale Design
Feed rate, gpd	16,000	30,000,000
Recycle, % of feed	26	25 (15-35)
Overflow[a] rate, gpm/ft^2	1.22	3.80
Air saturation pressure, psig	50	50 (20-60)
Alum usage, mg/l	50	50 (0-100)
Polyelectrolyte usage, mg/l	0.2	0.2 (0-1.0)
Flocculator speed, circumferential, fps	1.3	1.0 - 3.0
Flocculator retention time, minutes	11.8	18.0
Flotation retention time, minutes	13.7	19.5

[a] Based on feed rate plus 25% recycle.

The pilot unit exhibited the following typical performance:

Specific Contaminant	Feed	Effluent	% Removal
Jackson Turbidity Units	70	4	94
Suspended Solids, mg/l	40	8	80
I. R. Oil, mg/l	80	5	94

The only design parameter that is significantly different in the full-scale unit is the overflow rate, gpm/ft^2 of flotation surface. However, an overflow rate of 3.60 gpm/ft^2 was not considered critical since rates as high as 4 gpm/ft^2 are not uncommon. The full-scale unit would have more residence time in both the flocculator and flotation sections.

REYNOLDS NUMBER EFFECT

One factor that could not be adequately compensated for in the scale up was the effect of the larger cross-sectional area on Reynolds Number and the increased turbulence. The full-scale unit has a Reynolds Number roughly 40 times greater than the pilot unit. While the pilot unit operated at the upper limit of streamline flow, the full-scale unit operates in the turbulent region. This turbulent condition and the excessive water depth could be factors accounting for the poorer performance of the full-scale unit relative to the pilot unit.

This variable will be evaluated in the pilot plant and in a single, modified chamber in the air flotation unit.

ALUM ADDITION AND FLASH MIXING

The pilot plant tests indicated that mixing time of 1-2 minutes was necessary to adequately coagulate the colloids with alum to promote optimum coagulation. The flash-mix zone of the full-scale unit was designed to take advantage of residence time in the influent channel to the AFU as well as the extra residence time in the influent channel to the AFU as well as the extra residence time available in the flocculators. The average residence time in the influent channel is about 2.5 minutes while there are six minutes of excess residence time in the flocculator. Accordingly, the flash-mix zone was designed for a residence time of about 1.0 minute. Mixing energy is supplied by a four-bladed, axial-flow impeller, turning at 68 rpm, and driven by a 30 hp motor.

POLYELECTROLYTE ADDITION SYSTEM

Polyelectrolytes are high molecular weight polymers that aid flocculation and toughen the alum floc. Dosages of 0.2 mg/l polyelectrolyte were usually beneficial on the pilot plant. The system was designed to permit controlled addition of polyelectrolyte solution to each of the seven flocculator boxes.

The polyelectrolyte addition system shown in Figure 5 consists of a polymer mix tank, a polymer feed tank, a nonshearing metering pump, and a distribution manifold. The mix tank is sized for batches of 2,400 gallons of 0.25 per cent solution. The 5,000-gallon polymer feed tank will hold two such batches. To aid the distribution of the polymer, recycle water is added continuously as diluent to the discharge of the metering pump.

FLOCCULATOR CELLS

The first stage of each of the seven API separator boxes was modified to serve as a flocculator cell. A sketch of a flocculator cell in elevation view is shown in Figure 6. Water enters the inlet trough at the right side through multiple conduits, overflows the inlet weir, underflows the trough into the flocculator cell. The flocculators can be rotated with a peripheral speed of 1 to 3 fps. Polyelectrolyte is added at the inlet weir.

At the outlet, the water underflows the outlet baffle and enters the air flotation chambers through multiple conduits.

AIR FLOTATION CHAMBERS

The second stage of each of the API separator boxes was converted to flotation chambers conforming to the design shown in elevation view in Figure 7. Water from the flocculator enters at the right side, is joined by the pressurized recycle water in the contacting zone, moves through the flow distribution baffle into the flotation chamber, and finally underflows the outlet baffle into the effluent channel. The floated material is skimmed into the scum trough where a screw conveyor moves it to a sludge sump from which it is transferred to tankage and ultimately to incineration. Until the incinerator is constructed, the skimmings are disposed of by landfilling and land-spreading operations.

Figure 5

Polyelectrolyte addition system

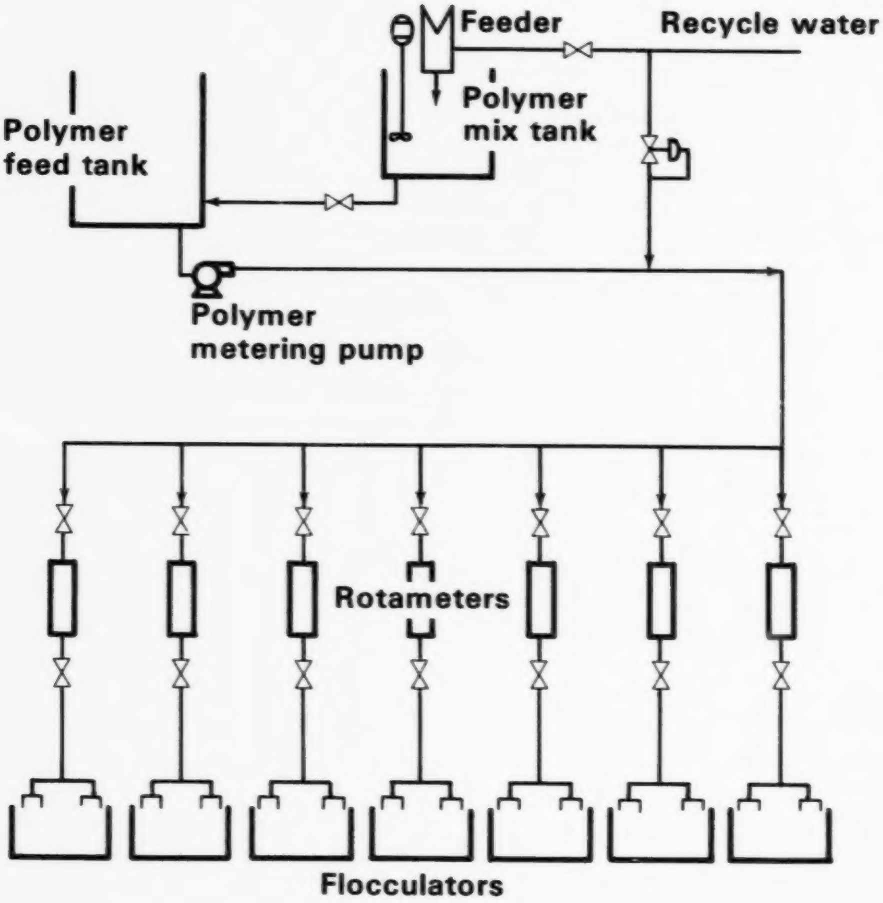
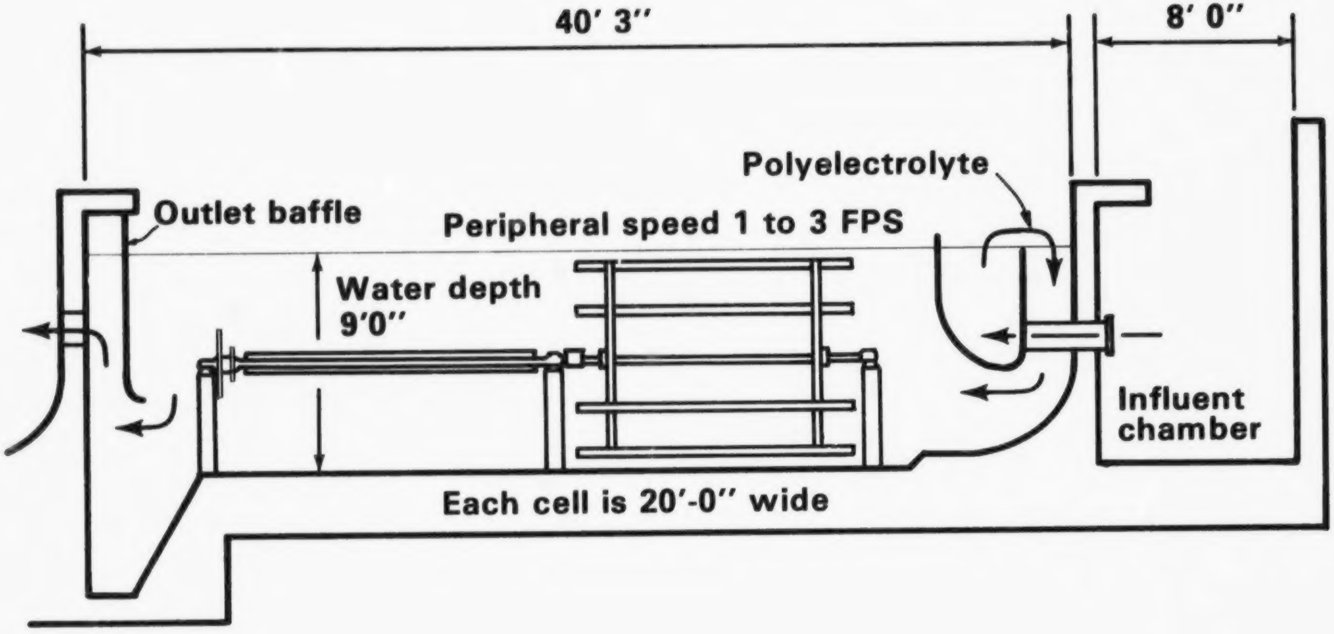

Feeder
Recycle water
Polymer mix tank
Polymer feed tank
Polymer metering pump
Rotameters
Flocculators

Figure 6

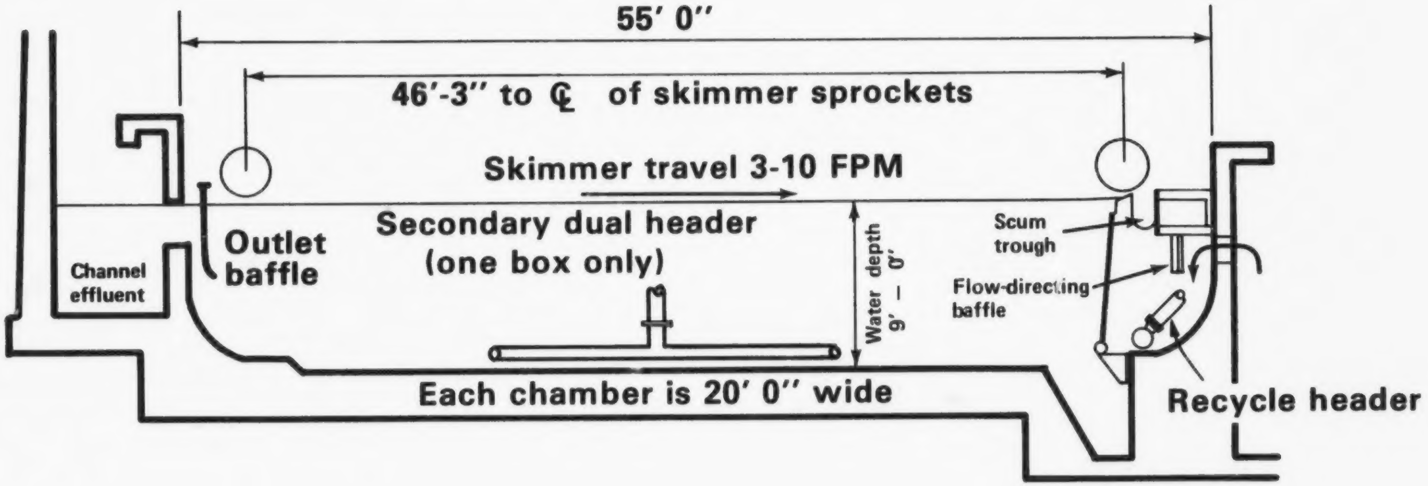
Flocculator cell



40′ 3″
8′ 0″
Polyelectrolyte
Outlet baffle
Peripheral speed 1 to 3 FPS
Water depth
9′0″
Influent
chamber
Each cell is 20′-0″ wide

Figure 7

Flotation chamber


55′ 0″
46′-3″ to ℄ of skimmer sprockets
Skimmer travel 3-10 FPM
Secondary dual header
(one box only)
Outlet
baffle
Channel
effluent
Water depth
9′ – 0′
Scum
trough
Flow-directing
baffle
Recycle header
Each chamber is 20′ 0″ wide

RECYCLE WATER AND FLOTATION AIR

Recycle water for the seven air flotation chambers is supplied by one pump, with a spare that is used simultaneously when recycle rates in excess of 25 per cent are desired, but each chamber has its own air saturation drum. The flow rate to each chamber, as shown in Figure 8, is manually controlled. The water enters the top of the air saturation drum and rains down through the air at 50 psig to the pool at the bottom. The liquid level control opens and closes an air bleed on the top of the drum to maintain a preset level. Residence time is about 20 seconds at 800 gpm. Water leaves the air saturation drum and is depressurized at the pressure reducing valve. The depressurized water drops vertically a distance of about 13 feet to the recycle distribution header in the contacting zone. Experimental work has shown that this recycle water is 90-95 per cent saturated at 50 psig. The saturation air was determined by weighing the pressurized recycle water from the air saturation drum into a barrel and measuring the displaced and released air through a calibrated, wet test meter. The test was run six times with good repeatability, ± 5 per cent.

SECONDARY RECYCLE HEADER

A dual, secondary recycle header was installed at the midpoint of the flotation chamber of one unit. See Figure 13, page 42. The secondary recycle provides additional flotation air by increasing the gross recycle rate and, thereby, a second and third chance to float coagulated floc without hydraulically loading up the front end of the flotation chamber. Performance of this chamber relative to other chambers will measure its effectiveness (Section VII).

GENERAL PROCESS FLOW

The entire air flotation unit is shown in plan view in Figure 9 and in the photograph, Figure 10. An alternate to the previously described polyelectrolyte addition point is shown.

The effluent from the biopond flows by gravity through an open, below-grade channel into the flash-mix zone, then into the influent channel to feed the seven parallel-operating, flocculator-flotation chambers. The original design provided for alum addition to the

Figure 8

Recycle system

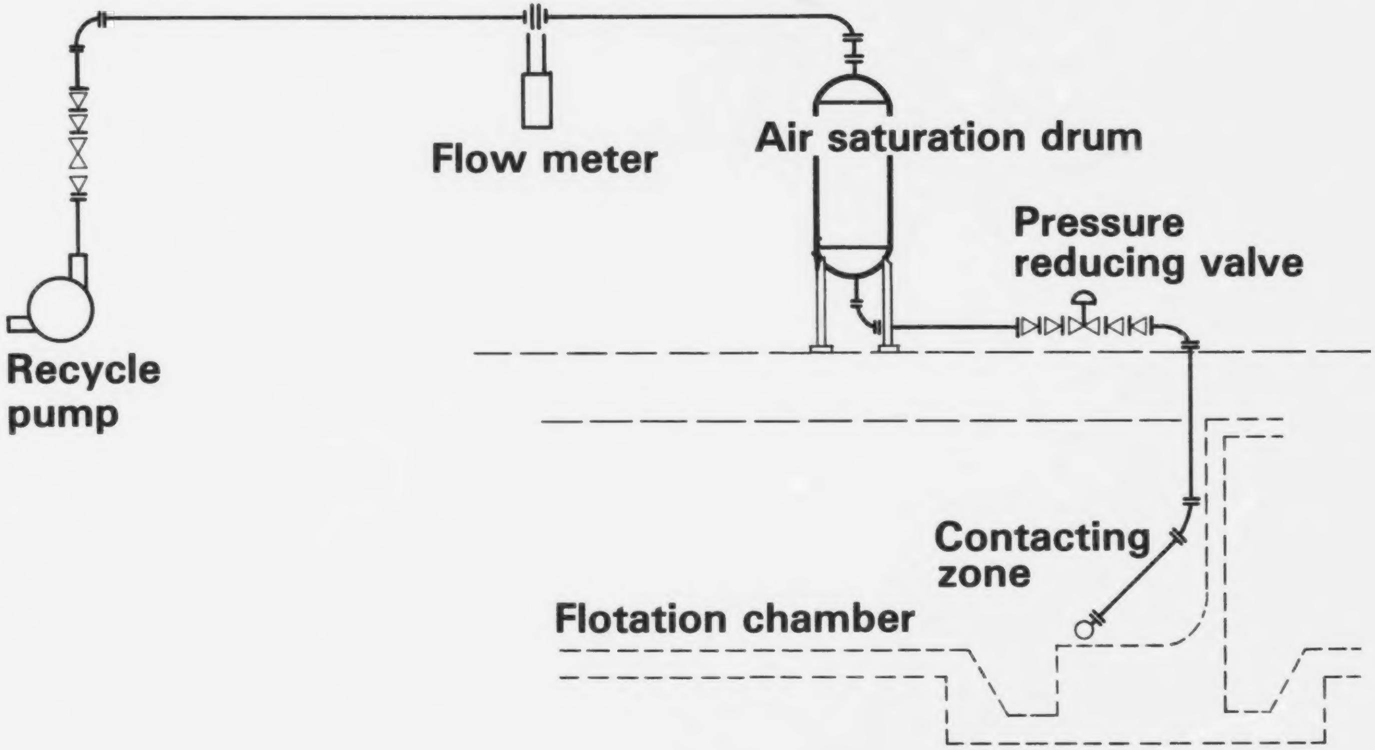

Flow meter
Air saturation drum
Pressure
reducing valve
Recycle
pump
Contacting
zone
Flotation chamber

Figure 9

Plan view of air flotation unit

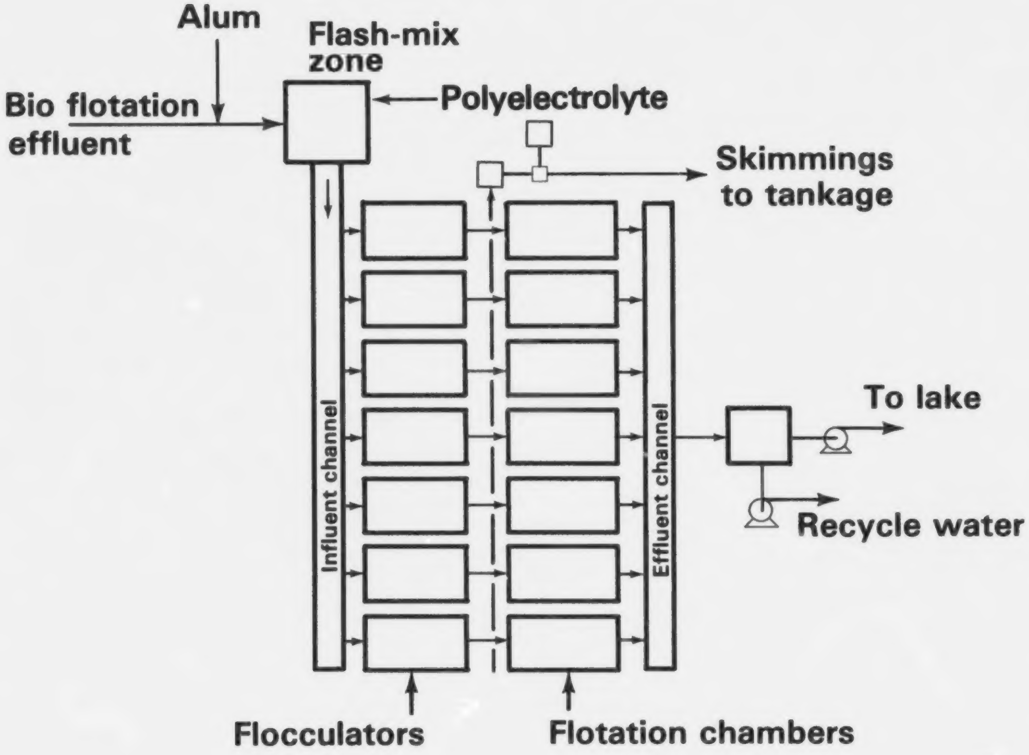
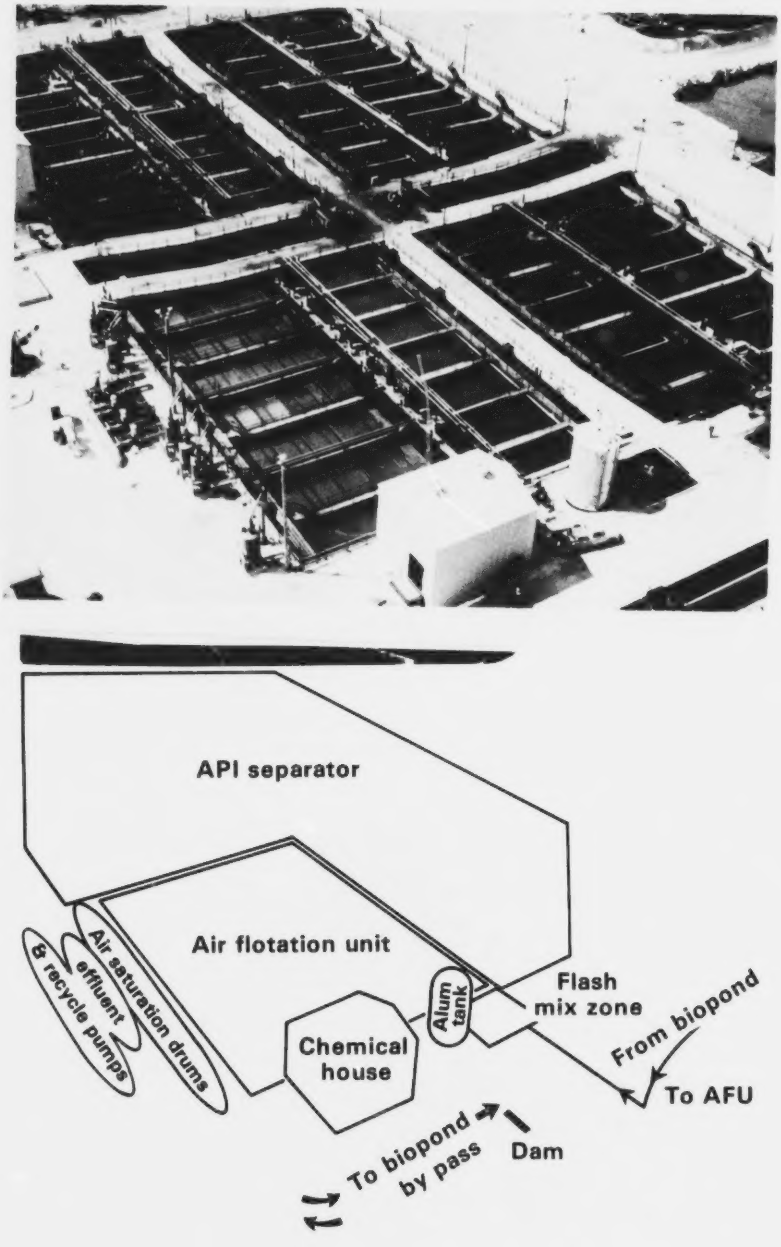

Alum
Flash-mix zone
Bio flotation effluent
Polyelectrolyte
Skimmings to tankage
Influent channel
Effluent channel
To lake
Recycle water
Flocculators
Flotation chambers

Figure 10
Photograph of air flotation & API separator


API separator
Air flotation unit
Air saturation drums
effluent & recycle pumps
Chemical house
Alum tank
Flash mix zone
From biopond
To AFU
To biopond by pass
Dam

flash-mix zone, and polyelectrolyte addition to each flocculator at its inlet weir. The 48 per cent hydrated aluminum sulfate plus 52 per cent free-water solution are currently added a short distance upstream of the flash-mix zone. Each flocculator chamber is equipped with a pair of paddles providing mild agitation to promote flocculation. The treated water then flows through a conduit into the contact zone of the flotation chamber where it is joined by the aerated, pressurized, recycle water near the floor. The combined streams flow through a distributor into the flotation chamber. The released air adheres to the flocculated solids and floats them to the removal trough. Clarified water from each flotation chamber flows into the effluent channel where the recycle pump returns water to each of the seven air saturation drums and the net water is pumped to a point of discharge.

SECTION 6

INITIAL OPERATION AND DESIGN MODIFICATIONS

Initially, the AFU performed very poorly. Problems involving gross air release downstream of the pressure-reducing valve, violent bubbling of air through the scum layer in front of the beach, and inefficient scum removal resulted in poor performance. Having seven parallel-operating units made it possible to try different remedies at the same time. Different observers attributed the initial, poor performance to inadequate mixing in the flocculator, too violent a contact between recycle water and delicate floc in the contact zone, sinking of scum due to the bubble agitation, and inefficient scum removal.

LOCATION OF PRESSURE-REDUCING VALVE

The location of the pressure-reducing valve relative to the distribution header proved to be a critical design factor. If the water is nearly saturated with air under pressure, air begins to release immediately after the pressure is reduced; therefore, the aerated recycle water should be discharged into the contact zone immediately upon depressurization. With a below-grade, modified API separator, it is not practical to locate the pressure-reducing valve below the water level; on this unit, the valves are located about 13 feet above the distribution headers. Because of the low pressure drop in the downstream piping, the vena contracta of the pressure-reducing valve produced a zone of subatmospheric pressure (a vacuum) which hastened the release of the dissolved air in the form of large bubbles totally unsuitable for air flotation.

The problem was overcome by putting some pressure drop into the downstream section of the piping. In two of the units, a multiple-hole orifice plate to provide some pressure drop was installed in a flange about nine feet above the distribution header. In three of the units, a similar orifice was installed about eight feet lower, at the inlet to the distribution header. In two of the units, the distribution header outlets were fitted with restriction orifices to take almost all of the pressure drop, essentially negating the need for the pressure-reducing valve. While all modifications work equally well, as shown in Section VII, Table 2, the restriction-orifice header design has a limitation in that recycle rate cannot be varied independently of air saturation pressure.

ENTRAPMENT OF FLOTATION AIR UNDER THE BEACH

The configuration of the beach and scum trough directly above the recycle distribution manifold shown in Figure 11 traps the entrained and gross air that rises to the surface in the area under the beach. The only way for the trapped air to vent from this enclosure was to bubble up in front of the beach in very large bubbles. The gross bubble problem was overcome by installing a high-point vent to release the trapped air outside of the flotation area.

SCUM REMOVAL

A clean sweep of the scum is dependent on the depth of cut of the skimmer blade into the scum, the approach angle at the beach, and the fit of the skimmer blade on the beach. The beach is only 12 inches long and has a slope of 3-3/16 inches in twelve. With the level control system provided on this unit, a level change of more than 3-3/16 inches sometimes happens. To avoid spilling water into the scum trough, operators maintain the high-level alarm towards a low level on the beach. Thus, the water level was frequently below the beach approach. In this situation, the skimmer blade could not make a clean sweep. The low-level situation would also result in a partial skim, the skimmer blade would shave off part and leave part of the scum layer. To overcome this problem, the beaches were lengthened to 20 inches, and the reach of the skimmer blades was extended about two inches. The skimmer blades now cut through the scum layer into the water and make essentially a clean sweep each pass.

OTHER MODIFICATIONS TESTED

Removal of the Solid Flow Directing Baffle

This baffle is located in the flotation chamber and directs the water entering it from the flocculator downward toward the recycle header as shown in Figure 11. Removal of the baffle would avoid an acute change in direction of flow and thereby reduce the turbulence in the contact zone. There would be less tendency for the delicate floc to fracture, and separation efficiency should improve. This baffle was removed from Boxes 1, 2, 4, and 7. Comparative data, Section VII, Table 2, indicated that this change was neither beneficial nor harmful.

Added Eight Boards to Flocculator Mixer

Jar tests indicated that additional flocculation would make a larger floc. It was a debatable point whether a larger floc would improve phase separation; a more important factor is toughness of floc. However, Boxes 1 and 2 were modified to increase mixing by the addition of eight boards to the flocculator paddles. The additional boards did decrease the amount of short circuiting in the flocculator, but the benefit to separation efficiency was not detectable. (Section VII, Table 2)

Removal of Outlet Baffle

The outlet baffle is located at the outlet end of the flotation chamber and partly restricts the outlet area as shown in Figure 12. This baffle forces the effluent to flow downwards to escape the flotation chamber. Removal of this baffle would allow the water to flow straight through the chamber and thereby minimize the downward currents that interfere with flotation. Contrary to the expected effect, quality of the effluent degraded when this baffle was removed, and, therefore, the outlet baffle was replaced.

Secondary Recycle Header

No. 7 box was constructed with a secondary recycle header located at the midpoint of the flotation chamber. This design modification provided for dividing the recycle between the normal contact zone and the flotation chamber proper to spread the supply of flotation air over a greater area. This design appears to offer a more efficient use of the flotation air.

Because of severe turbulence above the secondary recycle header, and unsatisfactory performance, the design was modified to split the secondary recycle into two parts, as shown in Figure 13,

Figure 11

Detail of beach

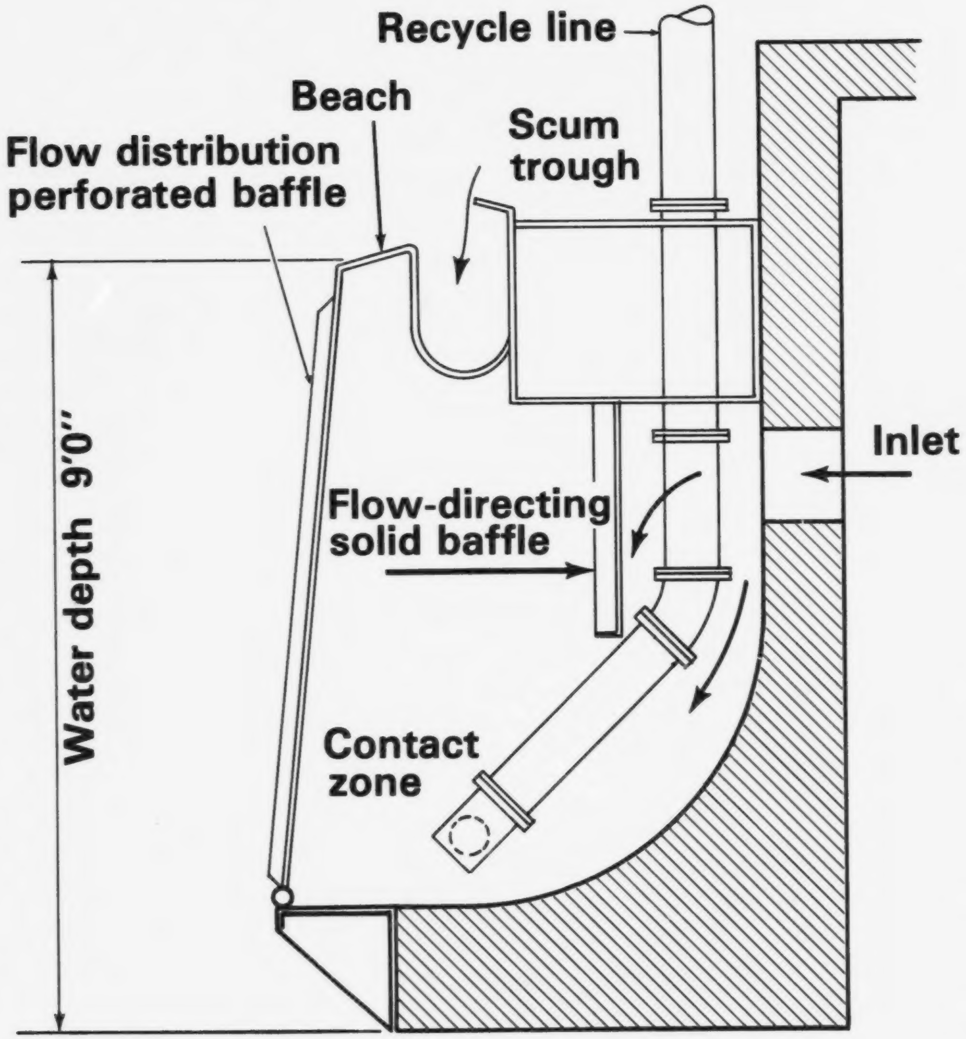

Recycle line
Beach
Scum trough
Flow distribution perforated baffle
Water depth 9'0"
Inlet
Flow-directing solid baffle
Contact zone

Figure 12

Location of outlet baffle

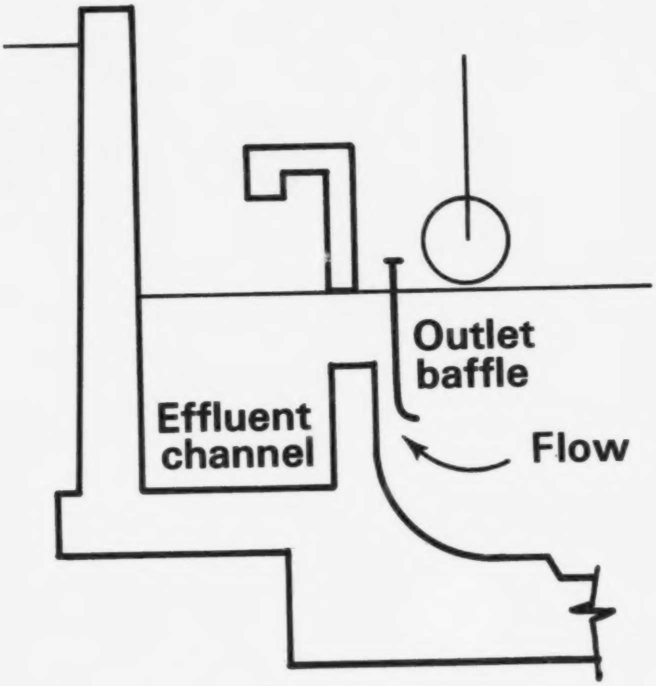
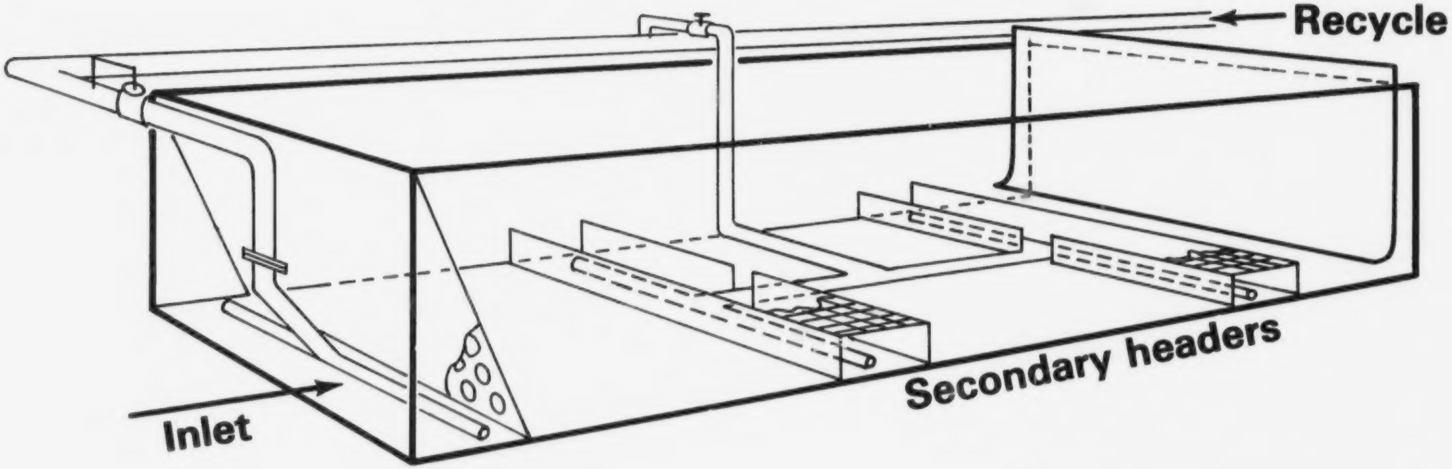

Outlet baffle
Effluent channel
Flow

Figure 13

Secondary recycle header design


Recycle
Secondary headers
Inlet

boxing in the headers and covering the tops with 1/8-inch mesh screens to dissipate turbulence. This design gave good distribution of flotation air for only one week. After that time, large air bubbles began to appear. Examination of the header installation showed that the screens had become growth centers for the slimes which acted as coalescing media for the flotation air.

The headers were again modified. This time, the screens were removed and the orifice outlets were directed upward, but a tee was welded to each outlet. This design avoids a trap to accumulate bubbles of air, and the tee acts as an impingement plate to dissipate the high orifice velocity. This design is performing satisfactorily. There are no large air bubbles, jet turbulence is not apparent, and distribution of flotation air is good. However, the secondary header design does not appear to give any better phase separation than the single recycle header design. Refer to Appendix A, Tables 2, 3, and 4.

In summary, the critical mechanical design modifications included the following:

1. Elimination of the in-line vacuum on the downstream side of the pressure-reducing valve.

2. Venting of the beaches to stop the severe bubbling of the entrained and coalesced air through the scum in front of the beaches.

3. Lengthening of the beaches to improve contact between the skimmer and the beach for more efficient scum removal; i.e., less water entrained. Water can be seen running down the beach under the blade. A longer beach will let more water run out and produce a drier scum.

4. Lengthening the skimmer blades so that blades extend through to water and make a clean sweep of scum each pass.

Optimum Addition Point for Chemicals

Throughout the initial operations period, many qualitative observations were made to determine the best location for the addition of alum and polyelectrolyte. Recognizing that coagulation may be benefited by additional contact time, the alum addition point was moved upstream of the flash-mix zone, a distance equivalent to about 20 seconds of contact time. At this point, the stream turns 90° and drops three feet, producing considerable turbulence.

Because there was no discernible difference in performance and because of the operating convenience it afforded, the upstream location for alum addition was permanently adopted. Concurrent with these observations, similar tests were conducted to find the optimum addition point for the anionic polyelectrolyte.

The effect of adding anionic polyelectrolyte at various locations in one box was compared to the design, four-point addition header in an adjacent box. The various locations included single-point addition at the middle and at the outlet of the flocculator cell. A multiple-point addition header (a garden soaker hose) was tested across the flow at the inlet weir and at the center of the flocculator cell as well as parallel to flow. From visual observations, the method of addition did not affect the size of the floc nor its apparent toughness. Several sequential tests were conducted comparing overall unit performance with the polyelectrolyte added first at the design location and then to the flash-mix zone. Again, there was no significant difference in performance as measured by turbidity readings. A point in the flash-mix zone near the inlet was selected as the permanent point of addition for anionic polyelectrolyte, because it simplified flow control and eliminated the chore of routine cleaning of slime from the seven rotameters.

SECTION 7

PROCESS VARIABLES

COMPARATIVE PERFORMANCE OF AIR FLOTATION CHAMBERS

Following the completion of the design modifications as outlined earlier, a number of tests were carried out to compare the performance of the individual flotation chambers. The total flow was divided equally among the seven units, recycle was held at 800 gpm on each, and air saturation pressure was set at 50 psig. Unit performance was compared by measuring the per cent reduction in turbidity. The average of 40 sets of data and the standard deviations are shown in Table 2 along with a listing of the devices for controlling pressure drop in the recycle header.

No significant difference could be determined between the performance of the seven boxes when evaluated by turbidity.

Slimes grow in the clear water, and deposits collect continuously in each flotation chamber. Periodically, this material will slough off and cause that particular chamber to appear to be malfunctioning. About 10 per cent of the daily samples indicate this type of unloading activity. Since there are ecological objections to chlorine and other biocides, no attempt was made to control the slime growth by their use.

FLOCCULATOR

The impact of flocculator speed on optimizing floc characteristics, which resulted in best phase separation by air flotation for the chemical treatment used, was evaluated by sampling at various locations in the system and using jar tests to estimate the efficiency with which the floc could be removed. Tests were conducted on parallel units operating at different flocculator speeds. Evaluation was carried out on samples that were carefully dipped into gradu-

Table 2. COMPARATIVE PERFORMANCE OF INDIVIDUAL FLOTATION CHAMBERS

Flotation Chamber	% Turbidity Reduction[a]	Standard Deviation	Pressure Drop Device in Recycle System
1	81.5	6.	Orifice Plate at Header
2	79.5	9.	Multi-Orifices in Header
3	83.5	6.	Orifice Plate at Header
4	80.5	7.	Orifice Plate at Header
5	80.5	7.	O.P. at Upper Flange
6	79.5	7.	O.P. at Upper Flange
7	80.5	7.	O.P. at Prim. & Sec. Hdrs.

[a] Basis: Inlet turbidity = 30-50 JTU

ated cylinders (to minimize breakage of floc) from selected locations in the flocculator cell, contacted with 25 per cent of air-pressurized water, and allowed to stand quietly for ten minutes. At that time, a small sample was withdrawn from the lower third of the graduated cylinder for a Jackson turbidity reading. Samples were dipped at the inlet weir, at the center, and at the outlet of each flocculator cell. Samples were also obtained from the outlet of the flotation chamber; these were not contacted with air-pressurized water and were used to compare the performance of the unit with performance predicted by jar tests. The per cent reduction in turbidity was used as the performance criterion. The test data are listed in Table 3.

For water quality existing at the time of the test and the chemical treatment used, these data indicate the following:

1. Some movement of the flocculator paddles is beneficial. However, a speed above the minimum at which our cells can operate, 1.0 foot per second, was not any better.

2. The flocculator center and outlet samples show the same degree of turbidity reduction indicating that half or even less of our flocculator length might be sufficient.

3. The natural turbulence in the flotation chamber produces poorer product than the flotation test cylinder, which is not surprising.

One set of flocculator outlet samples was also tested for oil and solids removal. Data comparing the minimum flocculator velocity of 1.0 fps to a shutdown flocculator are listed in Table 4.

The data on oil and solids removal show so little difference that one must conclude that added mechanical flocculator action contributes little if anything to unit performance. Apparently, there is adequate natural turbulence due to the flow characteristics of the flocculator cell to provide the necessary contact for good flocculation. However, the flocculators must run to assist in preventing scum from accumulating on the surface. Data in Appendix A, Tables 1, 2, 3, and 4 refute the premise that flocculation occurs to any major extent along the channel from the flash-mix zone

Table 3. PER CENT TURBIDITY REDUCTION IN BIOPOND EFFLUENT AS A FUNCTION OF FLOCCULATOR SPEED[a]

Peripheral Speed (fps)	Sampling Point			
	Flocculator			Air Flotation Chamber Outlet
	Inlet Weir	Center	Outlet	
0.0 (Shut Off)	80	80	80	74
1.0 (Min. Speed)	81	87	88	80
2.5 (Max. Speed)	81	86	86	81

[a] Basis: Biopond effluent turbidity range = 40-50 JTU

Table 4. PER CENT REDUCTION OF OIL AND SOLIDS AS A FUNCTION OF FLOCCULATOR SPEED[a]

Peripheral Speed, fps	Per Cent Reduction	
	Oil	Solids
0.0	50	38
1.0	48	44

[a] Basis: Inlet I.R. Oil = 30-70; TSS = 20-30 mg/l

to the boxes. Box No. 7 is the closest to the flash-mix zone; yet it and No. 6 are better, as measured by turbidity, than more distant boxes.

OPTIMUM RECYCLE RATE AND AIR SATURATION PRESSURE

The design basis for the air flotation unit was a recycle rate of 25 per cent (30 MGD process water rate) and an air saturation pressure of 50 psig. By operating the spare recycle pump in parallel, recycle rates up to 35 per cent can be attained. Tests of relatively short duration, two to four hours, were conducted at 30 psig and 50 psig at recycle rates per chamber of 500 gpm, 800 gpm, and 1,000 gpm which are equivalent to 17 per cent, 27 per cent, and 33 per cent recycle, respectively, based on fresh feed of 3,000 gpm/chamber. A set of grab samples was taken at the base condition after which new conditions were set and allowed to reach equilibrium and then a second set of grab samples was taken. These samples were tested for turbidity, I.R. oil, total suspended solids, pH, and sulfonates. Turbidity was determined on the individual flotation chambers. The percentage removal of turbidity, I.R. oil, and total suspended solids determined the performance at each set of conditions. The detailed test data are listed in Table 1 in Appendix A. The averages of the test data at an air saturation pressure of 50 psig are listed in Table 5.

The percentage reduction in oil content and suspended solids content is substantially better at 27 per cent recycle than at 17 per cent recycle. Increasing the recycle rate from 27 per cent to 33 per cent did not further improve the performance.

The tests at an air saturation pressure of 30 psig were limited to a maximum recycle rate of about 30 per cent because of high-pressure drops in the recycle piping. From data in Appendix A, Table 2, Tests 7 and 10, the average percentage reductions of turbidity, I.R. oil, and suspended solids are listed in Table 6. The negative solids data in Test 10 have been ignored as an obvious error.

At 30 psig air saturation pressure, as at 50 psig pressure, the higher recycle rate produces a better quality effluent. Turbidity and oil content were improved, but the solids content remained unchanged.

Table 5. EFFECT OF RECYCLE RATE ON PERFORMANCE AT 50 PSIG

Quality Parameter	Alum, mg/l	Recycle Rate, %		
		17	27	33
% Turbidity Reduction	33	65	84	
(Inlet = 25-35 JTU)	41	-	78	78
% Oil Reduction (I.R.)	33	47	78	
(Inlet = 25-50 mg/l)	41	-	72	67
% Suspended Solids Reduction	33	21	63	
(Inlet = 15-30 mg/l)	41	-	52	43

Table 6. EFFECT OF RECYCLE RATE ON PERFORMANCE AT 30 PSIG

	% Recycle at 30 psig	
	18	30
% Turbidity Reduction (Inlet = 40-50 JTU)	66	78
% I.R. Oil Reduction (Inlet = 40-65 mg/l)	61	76
% Solids Reduction (Inlet = 12-22 mg/l)	30	30

Tests 8 and 9 measured performance at air saturation pressures of 30 and 50 psig at 17 per cent and 27 per cent recycle. These tests summarized in Table 7 indicate that 27 per cent recycle is a better design choice than 17 per cent and that increasing the saturation pressure at 17 per cent recycle to provide more flotation air does not provide enough air to compensate for the reduced water volume.

COAGULANT ADDITION

Dissolved air flotation in the absence of an adequate coagulant is an inefficient means for phase removal. Bench-scale tests indicate a turbidity reduction of less than 25 per cent in the absence of alum. Although a coagulant is necessary, effluent quality can deteriorate from too much coagulant as well as too little. Theoretically, just enough alum is added to promote the coagulation of the colloidally dispersed solids. Jar test experience indicated that 30-50 mg/l of alum is sufficient to promote coagulation.

Other characteristics also influence the coagulation properties of the feed: (1) in a situation of neutral charges, the hydrophilic solids will be more difficult to separate than hydrophobic solids, and (2) negatively charged sulfonates tend to keep the oil and solids phases dispersed and difficult to separate. Sometimes the proper chemical treatment will overcome these properties, but it is difficult to predict which combination of treating chemicals is required to achieve the optimum effluent quality improvement. The following test data illustrate this point.

Difficult-to-Treat Feed

At a time before the sulfonate test was being used to characterize feed quality, a particular feed was not producing the expected effluent quality. The alum dosage was doubled without any benefit. Real quality improvement was not attained until the polyelectrolyte dosage was increased tenfold, from 0.2 mg/l to 2.5 mg/l. Detailed test data are listed in Table 3, Test 11, in Appendix A and summarized in Table 8.

Separation was poor because air bubbles would neither adhere to nor be entrapped in the small floc particles. The massive dosage of the anionic polyelectrolyte probably promoted bridging of several small flocs which then more effectively trapped the air bubbles.

Table 7. COMPARISON OF 30 AND 50 PSIG SATURATION PRESSURES AT 17 AND 27% RECYCLE RATES

	% Recycle at			
	30 psig		50 psig	
	17	27	17	27
% Turbidity Reduction (Inlet = 42-52 JTU)	71	82	72	85
% I.R. Oil Reduction (Inlet = 41-66 mg/l I.R. Oil)	66	82	68	88
% Solids Reduction (Inlet = 12-22 mg/l)	8	35	35	-

Table 8. PERFORMANCE ON DIFFICULT-TO-TREAT FEED

Alum Rate mg/l	Anionic Polymer mg/l	% Reduction		
		Turbidity	I.R. Oil	Solids
35	0.20	58 (38)[a]	20 (24)	32 (25)
80	0.20	39 (38)	28 (49)	Neg. (14)
80	2.50	85 (38)	77 (49)	50 (14)

[a] Inlet value in parenthesis

Easy-to-Treat Feeds

Feeds that are easy to treat contain no sulfonates and have relatively low oil and suspended solids content. Such feeds show variable reactions to chemical dosage, but, frequently, anionic polyelectrolyte is of no benefit. A number of short-term demonstration tests were conducted, and the detailed data are listed under Tests 13a through 19b in Tables 3 and 4 in Appendix A. Alum dosages were varied from 25 mg/l to 200 mg/l and anionic polyelectrolyte from nil to 0.41 mg/l. The data were divided into groups of tests with polyelectrolyte and without polyelectrolyte and averaged. The data are summarized in Table 9.

There is no significant difference between the data of Group I and the data of Group II. The conclusion is that certain feeds are not benefited by polyelectrolyte.

Tests 11a, 11b, and 11c in Appendix A illustrate a phenomenon occasionally observed; i.e., certain waters reacted antagonistically to increasing alum concentration, but comparatively massive dosages of polyelectrolyte usually controlled this response and produced a highly clarified effluent.

Tests 12, 13b, and 14c evaluated the effects of increasing the alum dosage to 70-75 mg/l. The average of these data show an oil reduction of 72 per cent and solids reduction of 59 per cent. These results are not significantly different than the data from Group I and Group II above. Thus, additional alum above the minimum requirement is not beneficial and may be detrimental as in Test 11 without additional polyelectrolyte.

Tests 15a and 15b were conducted to determine the effects of a massive dosage of alum on effluent quality and unit performance. The test was of short duration because the large quantities of scum soon overloaded the scum handling facilities. The scum was an unusually aerated and stable foam that was difficult to pump. From this single test, the data show that a massive increase in alum had no effect on the oil content of effluent, but the solids content doubled, increasing from 11 mg/l to 22 mg/l. If one assumes that added alum (as $Al(OH)_3$) is part of the solids to be removed, the percentage reduction in solids content did not change, roughly 50 per cent in both tests. In this test, the water did not respond antagonistically toward the large alum concentrations.

Table 9. PERFORMANCE ON EASY-TO-TREAT FEED

Process or Quality Parameter	Group I Tests With Polyelectrolyte	Group II Tests Without Polyelectrolyte
Alum, mg/l	25 - 43	25 - 43
Anionic Polymer, mg/l	0.20 - 0.22	Nil
I.R. Oil, Reduction, % (Inlet = 35-70 mg/l)	69	71
Suspended Solids Reduction % (Inlet = 14-35 mg/l)	58	61

Comparison of Different Polyelectrolytes

More than 20 cationic, nonionic, and anionic polyelectrolytes were screened for their effectiveness as a flocculating aid using alum as the prime coagulant. The jar tests classified the polyelectrolytes according to reaction speed, clarity of the liquid phase, and apparent toughness of floc, which can be observed by speeding up the stirring. Based on these studies and performance in the pilot plant, Percol 155 (American Colloids) was selected for the initial operations. Subsequent jar tests indicated that WT 2700 (Calgon) would be equally good and that Atlasep 1A1 (Atlas Chemical) would be best of all. The jar test procedure is described in Appendix F.

The polyelectrolytes were compared by observing the performance in parallel flotation units. Two such tests were conducted. One test, on relatively clean feed, compared Percol 155 to WT 2700 to no polymer (blank test); the other on a refractory feed, compared Percol 155 to WT 2700 and Atlasep 1A1. The test data are listed in detail in Table 5 in Appendix A.

During the "clean-feed test," samples were carefully dipped from the outlet of each flocculator zone for visual inspection and jar flotation with 25 per cent pressurized recycle water. Percol 155 produced a larger floc and a clearer liquid phase than the WT 2700. In actual unit performance, the data in Table 10 show that there was no significant difference between either polyelectrolyte and no polyelectrolyte. Solids removal efficiency was poor in this test, probably because the solids level in the feed was exceptionally low, 13 mg/l.

Repeating the test with "dirty" water, samples were again carefully dipped from the outlet of the flocculator cells and air-floated in jars. There is no significant difference between the polymers.

The air flotation unit data in Table 11 does not classify these polyelectrolytes as distinctly as do jar tests.

Effect of Lime Addition On Phase Separation

A test was run to determine whether the addition of lime would improve phase separation. A bench test indicated that a 75 mg/l

Table 10. COMPARISON OF POLYELECTROLYTES ON THE AFU WITH "CLEAN" FEED

Quality Parameter	WT 2700	Percol 155	None
Turbidity Reduction, % (Inlet = 61 JTU)	82	87	85
I.R. Oil Reduction, % (Inlet = 74 mg/l)	74	70	76
Solids Reduction, % (Inlet = 13 mg/l)	23	Neg.	30

Table 11. COMPARISON OF POLYELECTROLYTES ON THE AFU WITH "DIRTY" FEED

Quality Parameter	PRODUCTS		
	Atlasep 1A1	WT 2700	Percol 155
Turbidity Reduction, % (Inlet = 380 JTU)	94	93	93
I.R. Oil Reduction, % (Inlet = 147 mg/l)	87	83	84
Solids Reduction, % (Inlet = 23 mg/l)	83	87	83

dosage of lime would be beneficial. The precipitated $CaCO_3$ would provide additional nuclei for the formation of minute air bubbles and improve removal of total suspended solids.

In this test, the alum and polyelectrolyte dosages were at 40 mg/l and 0.2 mg/l, respectively. Lime, at a dosage of 85 mg/l was added for a period of 70 minutes to one flocculator-flotation unit. At the end of the time period, grab samples of effluent were taken from adjacent units for analysis for total suspended solids and pH. The data are listed in Table 12.

The addition of lime not only caused an increase in total suspended solids but also imparted a color to the effluent. The increased color was not unexpected because earlier experience has shown that color increases with increasing pH.

Effect of Skimmer Speed On Effluent Quality

Effect of skimmer speed on unit performance was evaluated by comparing performance of parallel flotation chambers. Three units were set to skim at a rate of 8 feet per minute, and three other units were set to skim at a minimum rate of 3 feet per minute. The process water rate was 28 MGD and was treated with alum at 43 mg/l and polyelectrolyte at 0.21 mg/l. The water had a pH of 7.2 and was free of sulfonate contamination.

Grab samples of effluent and scum were taken from each of the flotation chambers for analysis. Data are listed in Table 13. The data show that performance efficiency is independent of skimmer speed in the range of 3 feet to 8 feet per minute.

During the initial operation of the unit, the skimmers were run intermittently, for 10-15 minutes every 2-3 hours. Based on a surge of solids showing in the effluent each time the skimmers started, it was concluded that continuous operation is preferable.

Initial Zeta Potential Studies

Zeta potential is believed to be one of the many factors affecting the performance of an air flotation unit. Determination of zeta potential is a difficult and delicate procedure and is not applicable to routine

Table 12. EFFECT OF LIME ADDITION ON AIR FLOTATION PERFORMANCE

	Suspended Solids, mg/l	pH
Control	7	7.4
Lime Addition	19	7.8

Table 13. EFFECT OF SKIMMER SPEED ON AIR FLOTATION PERFORMANCE

Quality Parameter	Slow Speed Composite (3 feet/min)	Fast Speed Composite (8 feet/min)
Turbidity Reduction, % (Inlet = 59 JTU)	82	82
I.R. Oil Reduction, % (Inlet = 55 mg/l)	73	71
Suspended Solids Reduction, % (Inlet = 24 mg/l)	71	67

operations. Subsequent to these plant tests, improved zeta potential instrumentation was obtained and this aspect further studied. Controlling the zeta potential was determined to be a key element in optimizing the efficiency of the air flotation unit for phase removal. This subsequent work is reported in the Addendum Section.

Effect of Sulfonate Contamination

The Whiting refinery produces a variety of different molecular weight of sulfonates as byproducts of sulfuric acid-treating operations for the production of white oils. These sulfonates are used in the formulation of many specialty products, including metal preservatives and soluble oils. During the course of manufacture, and the subsequent compounding operations, a small amount of these substances occasionally enter into the process sewer system. Such occurrences usually result in an increase in the oil content of the water throughout the three stages of water treatment and a deterioration of effluent quality.

A plot of the daily quality parameters does not show a clear relationship between effluent quality and sulfonate contamination. This is because other unidentified contaminants randomly entering the system similarly affect effluent quality. However, daily observations of unit operations indicate that effluent quality is generally unaffected by sulfonate contamination at concentrations below 5 mg/l but is invariably, adversely affected above 5 mg/l. Upsets were repeatedly observed in daily operations. The data in Appendix A, Table 4, Tests 18b, 19a, and 19b show the effect. More obvious is the effect on pilot plant tests as shown in Table 12, Appendix A, which is discussed later.

Incidents of sulfonate contamination have been infrequent due to intensive in-plant controls. The chance for such incidents will be even further reduced when the acid-treating operations are abandoned in the near future.

Factors Affecting Water Content of Scum

More than 150 Soxhlet extractions of scum samples show that water content can range from as little as 85 per cent to more than 95 per cent. A scum with 95 per cent water occupies three times the volume of a scum with 85 per cent water. Because the scum is a "solid-waste" without byproduct value, it must be disposed of as waste material. Any factors that influence the volume and heat content of the scum produced can be important process-control variables.

Preliminary tests indicated that water content of scum varied directly with skimmer speed; the faster the speed, the wetter the scum. A slow skimmer speed produces a drier scum, because it allows more time for the scum blanket to dry out on the surface of the flotation chamber and more draining time as the scum is moved up the beach into the removal trough.

Several sequential tests were conducted to measure the effect of skimmer speed on water content. One chamber was equipped with a low-speed gear reducer to permit evaluations down to a skimmer speed of 1 ft/minute. Scum samples were caught at the brink of the scum trough while operating the skimmer at a measured speed. Each sample consisted of a composite of three to four skimmer-flight dumps. The data from the eight series of tests are listed in Table 6 in Appendix A.

The water content data from units adjusted to speeds of 1 ft/min and 6 ft/min appear in Table 14.

An analysis of these data show that, assuming a linear relationship, for each 1 ft/min change in skimmer speed, the water content of the scum changes by 0.56 per cent. Thus, by reducing the skimmer speed from 3 ft/min (the normal minimum rate) to 1 ft/min, the water content can be reduced from 92.4 per cent to 91.2 per cent; this difference in water content represents a calculated reduction in scum volume of about 15 per cent.

Additional observations of skimmer operation reveal that, with the present spacing between flight scrapers, the minimum, practical skimmer speed consistent with the volume of scum produced is about 1 ft/minute. At slower speeds, the scum will frequently accumulate faster than it can be removed.

A more detailed examination of the data in Table 6 in Appendix B indicates that No. 2 Chamber consistently produces a drier scum than does No. 3 Chamber. The only physical difference between

Table 14. WATER CONTENT OF SCUM AS A FUNCTION OF SKIMMER SPEED

Test Number	Vol % Water at Skimmer Speed of	
	1 Ft/Min	6 Ft/Min
1	90.9	92.6
2	90.2	92.6
3	93.3	95.5
4	93.0	94.8
5	92.7	95.8
6	91.0	92.4
7	90.3	94.6
8	88.4	93.8
Avg	91.2	94.0

the two chambers is the design of the recycle system. The recycle water for No. 2 Chamber is depressurized through orifice outlets in the distribution header rather than by a pressure-reducing valve.

Perhaps the drier scum results because orifice outlets produce a greater number of small air bubbles which tend to entrap less water in the scum, or, possibly, they strip out more water as the small bubbles disengage from the scum. A summary of the data from four parallel tests comparing No. 2 Chamber to No. 3 Chamber is listed in Table 15; the table compares water content of the scum at a skimmer speed of 3 ft/min.

The difference between 91.3 per cent and 92.5 per cent water is equivalent to a calculated difference in scum volume of about 15 per cent.

A review of one year's operating data indicates that alum usage has the greatest effect on scum volume. The flocculant, hydrous aluminum oxide polymer readily attracts and entraps large quantities of water. In an air flotation unit, the wet alum floc is skimmed before it fully contracts and releases trapped water. The daily average alum usages and the corresponding daily average scum productions for each month of 1971 are listed in Table 7 in Appendix A; the data are also plotted in Figure 14. An analysis of these data indicates that one pound of alum will draw 28 to 35 pounds of water into the scum at 87 per cent to 93 per cent water content. On this basis, the water content of the scum can be expected to vary with alum dosage as indicated in Table 16.

Table 15. WATER CONTENT OF SCUM AS A FUNCTION OF RECYCLE HEADER DESIGN

Test	Water Content at 3 Ft/Min, Vol %	
	No. 2 Chamber	No. 3 Chamber
1	92.0	94.0
2	93.8	94.2
3	90.7	91.5
4	88.8	90.6
Avg	91.3	92.5

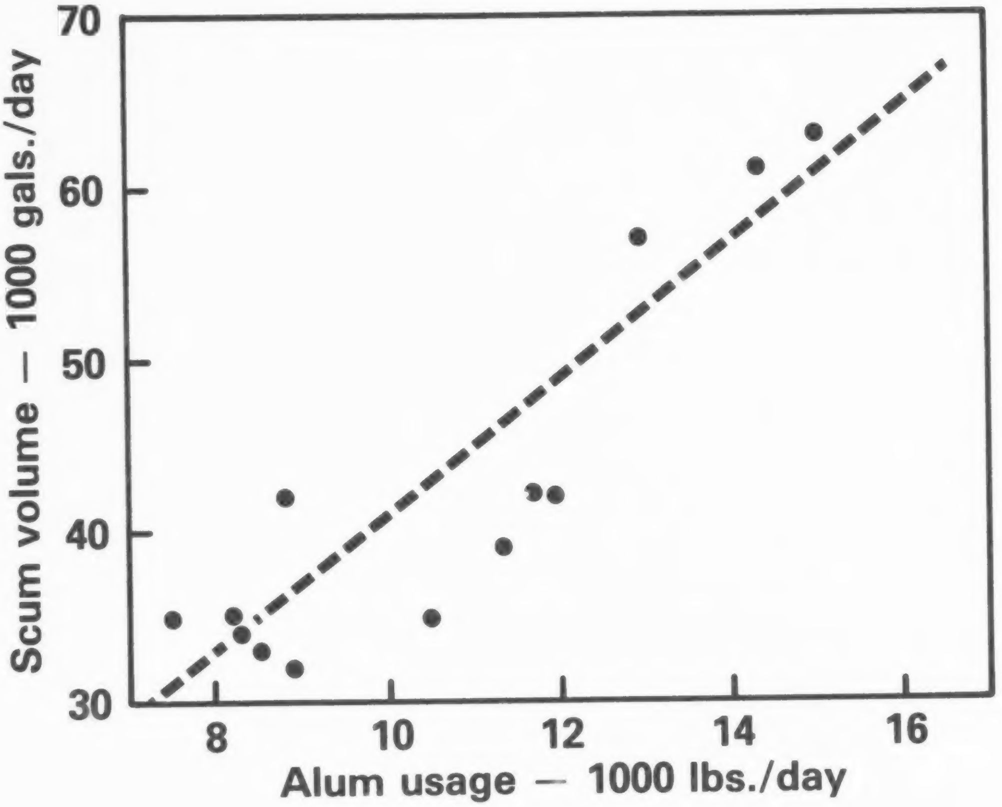
Table 16. WATER CONTENT OF SCUM AS A FUNCTION OF ALUM DOSAGE[a]

Alum Dosage mg/l	Water Content of Scum, %	Relative Volume
30	87	0.77
40	90	1.0
60	93	1.43

[a] When solids and oil contents of effluent are constant

Figure 14

Effect of alum usage on scum production



SECTION 8

PILOT UNIT COMPARISONS AND EVALUATION OF HYDRAULIC PARAMETERS

COMPARISON OF PILOT UNIT TO AFU

Because of the unexpected early poor performance of the AFU, the pilot unit was reactivated to operate in parallel with it. The pilot unit was operated at the design parameters and then under severe conditions in an effort to induce poor performance. Other tests were devised to measure the effects of Reynolds Number and overflow rate. The physical dimensions and layout of the pilot plant are illustrated in Figures 15 and 16.

Several parallel tests were run at design conditions with relatively complete analytical testing, including analyses for I.R. oil, total suspended solids, phenols, TOD, TON, turbidity, and total phosphates as PO_4. The percentage reduction of these parameters for the two units are compared in Figure 17.

The pilot unit did a better job of removing all contaminants than did the full-scale AFU. The pilot plant effluent was essentially equal to expectation from earlier studies; I.R. oil content was 5 mg/l, and total suspended solids was 6.5 mg/l.

The pilot unit showed stable performance over a wide range of flow rates. Changing flow rates, from 1/4 to two times the design rate, reduction in turbidity dropped from 95 per cent at the low rate to 92 per cent at the high rate. During the time of these tests, the AFU was achieving turbidity reductions in the range of 78-80 per cent.

The lower percentage removal of contaminants observed in the AFU is attributed to turbulence that is not present in the pilot unit. For example, at maximum recycle, the velocity of the recycle water issuing from the pilot unit manifold is only 1/4 of that of the full-

Figure 15

Air flotation pilot plant

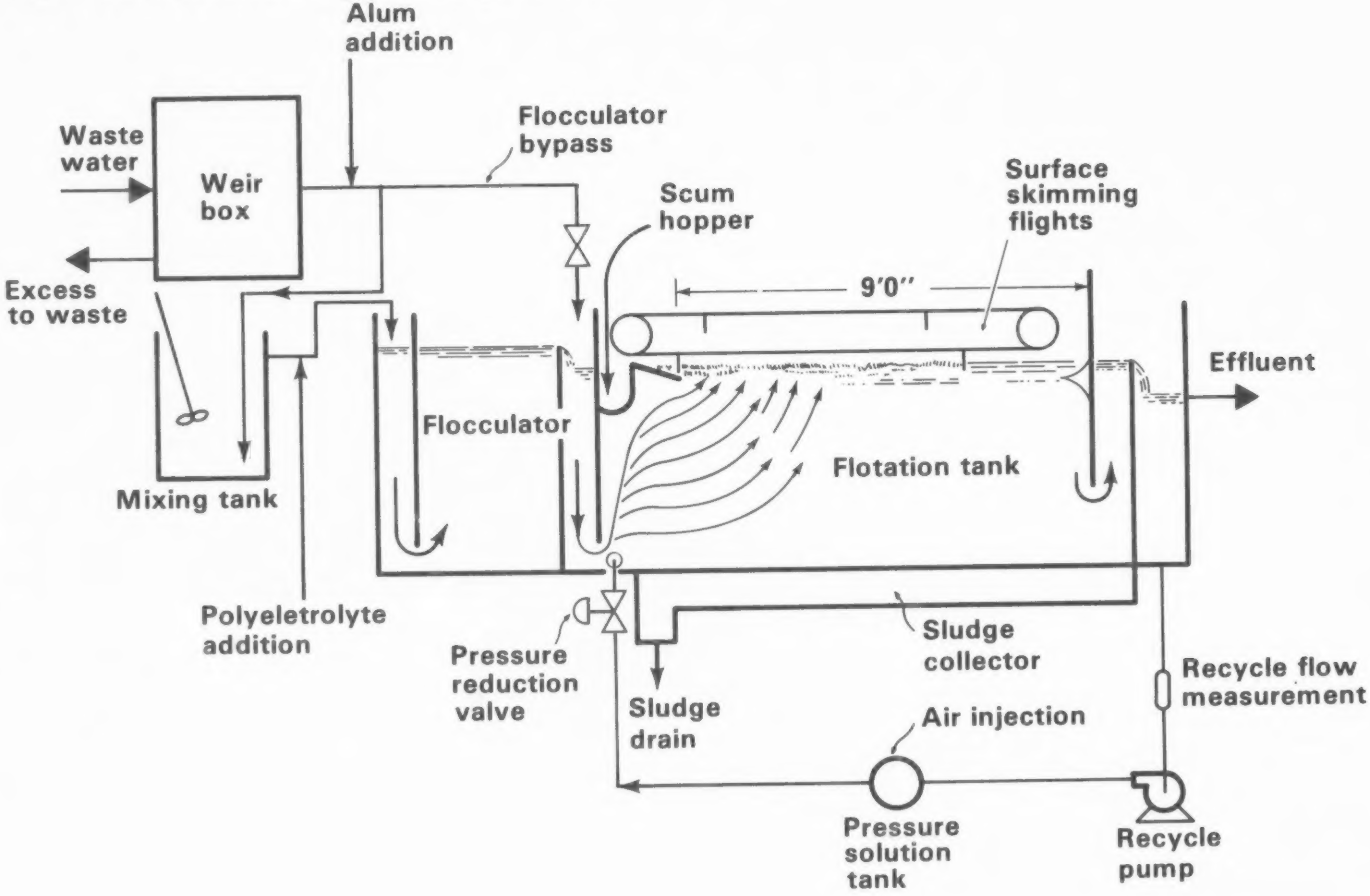

Alum addition
Waste water
Weir box
Excess to waste
Flocculator bypass
Scum hopper
Surface skimming flights
9'0"
Effluent
Mixing tank
Flocculator
Flotation tank
Polyeletrolyte addition
Pressure reduction valve
Sludge drain
Sludge collector
Air injection
Recycle flow measurement
Pressure solution tank
Recycle pump

Figure 16

Recycle area & end view of pilot plant

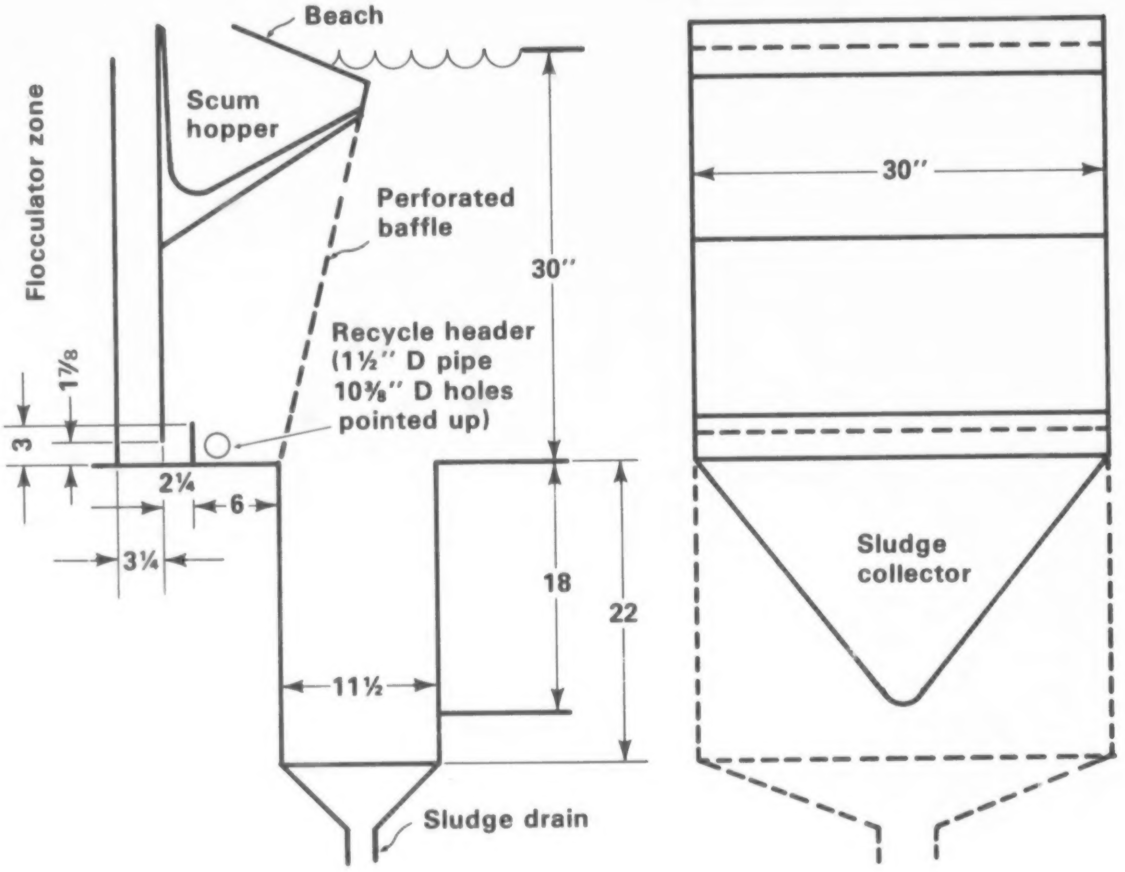
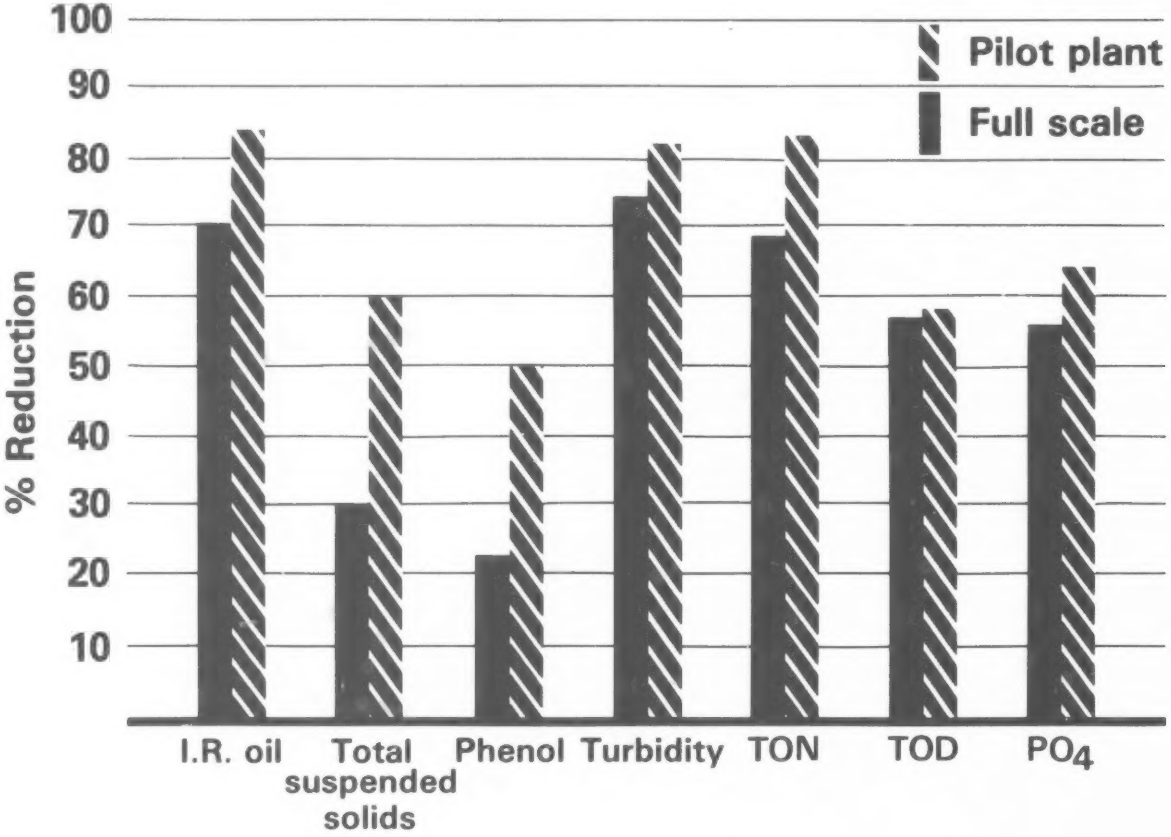

Beach
Scum hopper
Flocculator zone
Perforated baffle
30″
Recycle header (1½″ D pipe 10⅜″ D holes pointed up)
1⅞
3
2¼
6
3¼
11½
18
22
Sludge drain
30″
Sludge collector

Figure 17

Contaminant reduction, pilot plant compared to air flotation unit



scale unit. Tests were conducted at twice the design rate with half the header holes plugged to compare the effect of velocity on turbidity reduction. The effect of the presence of the distribution baffle was also measured in this test. The data are summarized in Table 17.

Table 17. EFFECT OF VELOCITY IN RECYCLE HEADER ON PILOT PLANT PERFORMANCE

Recycle Velocity in Header	% Turbidity Reduction	
	Baffle In	Baffle Out
1/4 of AFU Velocity	83	77
Equal to AFU Velocity	81	73

The data indicate that velocity in the recycle header is not critical but that the distribution baffle is required for optimum performance. The distribution baffle noticeably reduces turbulence in front of the beach.

The AFU experiences the release of gross air bubbles beneath the beaches which is not observed in the pilot plant. This was determined to be due partly to the long confined residence time of the recycle water following depressurization. When the distance between the pressure control valve and header was increased in the pilot plant so that the residence time before the header equaled that of the full-scale unit, a significant increase in gross air bubble formation was observed. However, the gross air produced in the pilot plant did not significantly impair its efficiency as measured by turbidity reduction.

SULFONATES EFFECT

Since the deleterious effect of sulfonates was not clear-cut in the AFU, a series of tests were made in the pilot plant at a time when sulfonates from the refinery were not present in the effluent and AFU operations were normal. The time selection was important because unidentified contaminants other than sulfonates do upset the AFU. From 5 to 25 mg/l of sodium lauryl sulfonate were added to the pilot plant influent and the inlet and outlet turbidities determined. Table 12, Appendix A, shows the data which indicates a tolerance of sulfonates up to 10 mg/l with a drastic effect at 18-19 mg/l and zero improvement at 25 mg/l. The AFU showed deleterious effect at about 5 mg/l, though by no means was it so apparent as in the pilot plant tests at 18 mg/l.

HYDRAULIC STUDIES IN PILOT PLANT

While it is not possible to duplicate the hydraulic parameters of the AFU in the pilot unit without serious distortions of residence time and overflow rate, additional studies were carried out to measure the effect of changing both Reynolds Number and overflow rate.

These hydraulic parameters were varied by positioning movable baffles in the flotation chamber to alter the overflow area and the hydraulic radius. These two dimensions were changed sufficiently to study the important hydraulic parameters over the ranges indicated in Table 18.

Table 18. RANGE OF HYDRAULIC VARIABLES IN PILOT UNIT STUDY

Overflow Rate	0.9 gpm/ft^2 - 13.2 gpm/ft^2
Linear Velocity	1.0 ft/min - 2.5 ft/min
Reynolds Number	4,100 - 10,200

Six series of tests were conducted with the normal chemical dosages of 40 mg/l alum and 0.2 mg/l anionic polyelectrolyte. Turbidity measurements were the primary gauge of unit performance. In the last series of tests, both suspended solids and I.R. oil content were determined. The test data are listed in Tables 8 and 9 in Appendix A.

The Reynolds Number (Re) test data are shown in Figure 18. Per cent turbidity reduction is plotted as a function of Reynolds Number and overflow rate. Physical dimensions of the pilot unit imposed a limit on the range. The maximum values tested were only one-tenth of the Reynolds Number of the AFU. However, over the range of 4,100 to 10,200 Re, unit performance is apparently independent of Reynolds Number. The data cluster in such a fashion to suggest that overflow rate is a significant variable.

For purposes of separating the effects of the water treatability from the hydraulic variable, the data were plotted two ways: Figure 19 shows per cent turbidity reduction as a function of overflow rate and linear velocity, and Figure 18 shows turbidity reductions as a function of overflow rate at various time periods in which feed quality varied. The data in both Figures 19 and 20 show a conclusive relationship between per cent turbidity reduction and overflow rate; that is, unit performance degrades with increasing overflow rate. The data plot encompasses the actual performance of the AFU; the 82 per cent reduction in turbidity at an overflow rate of 3.8 gals/min/ft^2 is within the range of the pilot unit test results at that time.

The relatively even distribution of the different linear-velocity data points in Figure 19 indicate that linear velocity is not an inherent variable. The same data replotted by date in Figure 20 appear to align into two groupings. The difference is thought to be a reflection of the difference in treatability.

Figure 21 shows the per cent reduction of I.R. oil and suspended solids as a function of overflow rate and linear velocity. These quality parameters are affected by overflow rate in the same manner as turbidity, but are independent of linear velocity.

These tests indicate that overflow rate is the hydraulic variable of major importance and that Reynolds Number is apparently an insignificant factor.

HYDRAULIC STUDIES IN THE AFU

The hydraulic factors leading to the poor performance of the AFU relative to the pilot unit could include: possible short circuiting, improper contacting of flocculator effluent with

Figure 18

Percent turbidity reduction as a function of Reynolds number

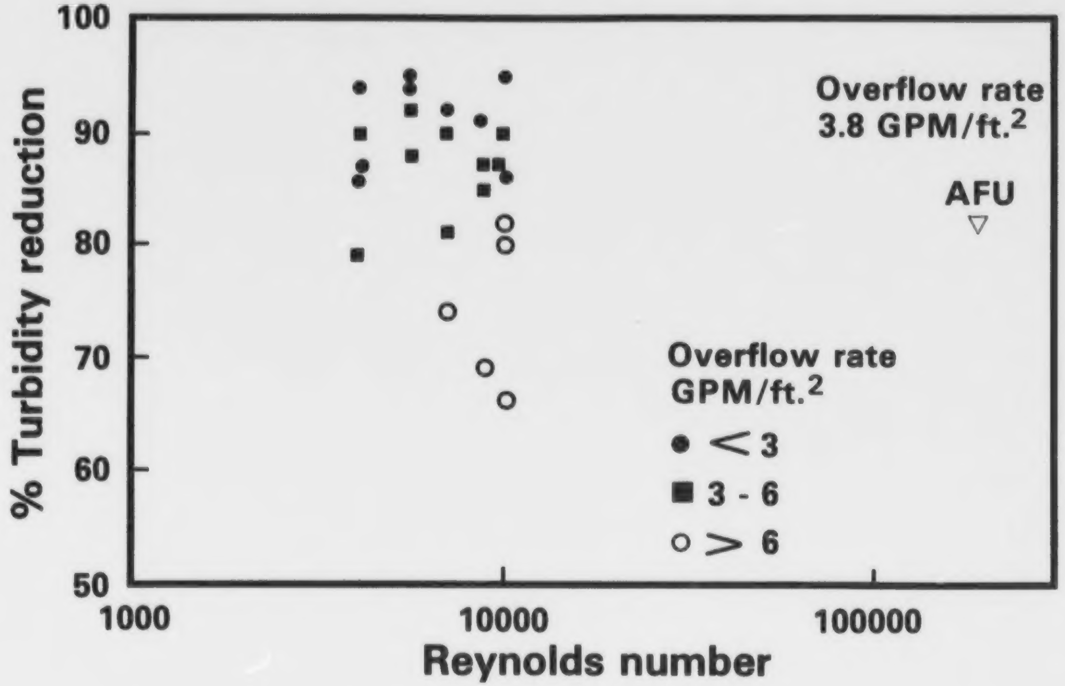


Figure 19

Percent turbidity reduction as a function of overflow rate and linear velocity

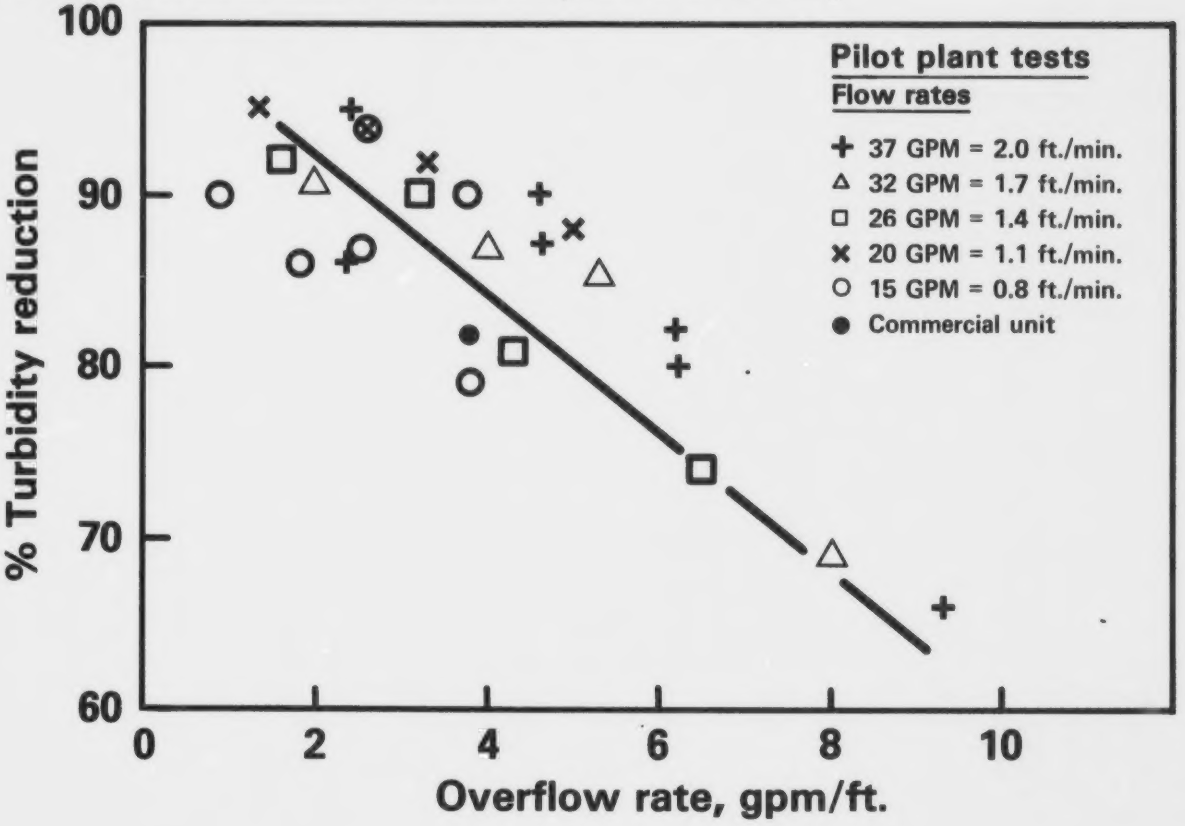


Figure 20

Percent turbidity reduction as a function of overflow rate and time

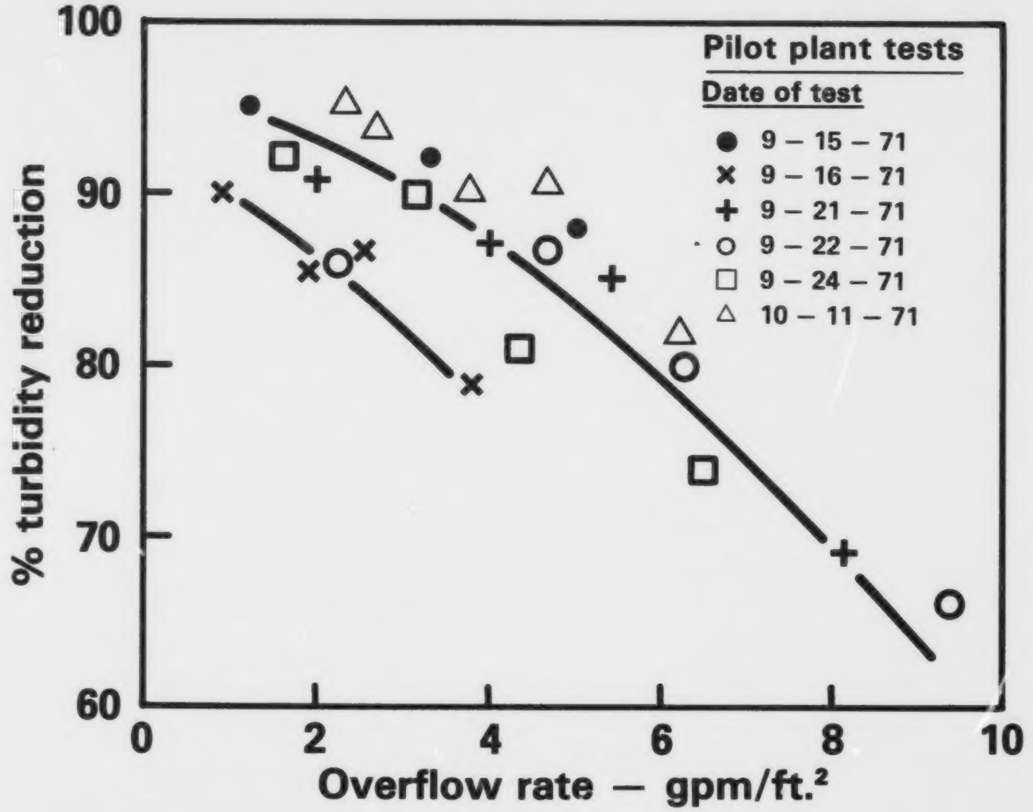
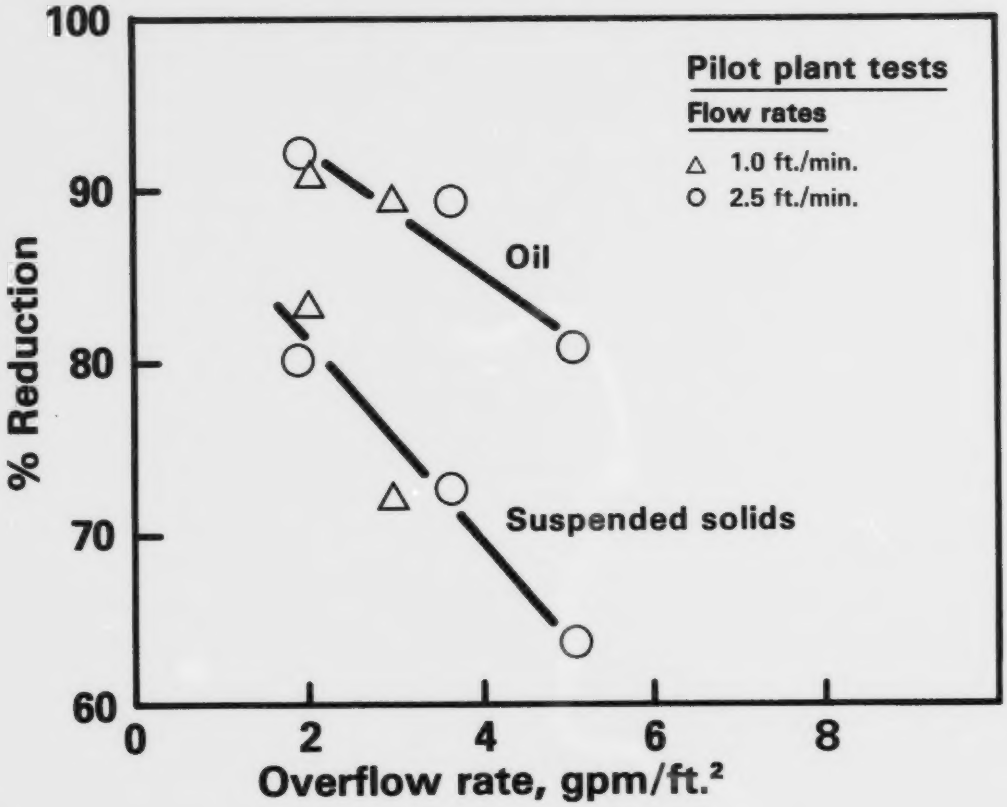


Figure 21

Percent reduction in contaminant content as a function of overflow rate



recycle water, too high an overflow rate, or turbulent mixing due to a high Reynolds Number. Special tests were devised to measure effects of short circuiting, overflow rate, and Reynolds Number.

Short Circuiting Tests

A dye test was conducted on each of the seven flocculator-flotation chambers to compare their hydraulic characteristics. The method of analysis developed by Villemont, Rohlich, and Wallace,[7, 8] was used to interpret the test results. The method involves plotting the dye concentration data on a dimensionless time scale (time of sampling/theoretical residence time) and then using several selected points as measures of the hydraulic characteristics. This method seems ideally designed for the flocculation section of the unit, since poor hydraulics hinder flocculation. The residence time curves of the combined flocculator-flotation chambers are not suitable for this method of analysis, because the several points of the curves used in this method are not well defined and may have been affected by recirculation of dye in the recycle water. Some of the important variables in this interpretation technique are:

Ti - the ratio of the initial appearance of the dye to the theoretical residence time

Tp - the ratio of the peak dye concentration time to the theoretical residence time

Tc - the ratio of the time interval that dye concentration is above one-half peak dye concentration to the theoretical residence time

Figure 22 shows a typical residence time curve and the points which correspond to Ti, Tp, and Tc. Curves for the individual chambers are not shown, but values of Tp, Tc, and Ti are listed in Table 19. For both Tp and Ti, the ideal values are 1.0 for ideal settling and zero for ideal mixing. For Tc, the ideal values are zero for ideal settling and 0.7 for ideal mixing.

Ti is a measure of severe short circuiting and generally is in the range of 0.07 to 0.28 for most rectangular basins. Tp is a measure of average short circuiting, dead spaces in the chamber, and

Figure 22

Typical residence time curve

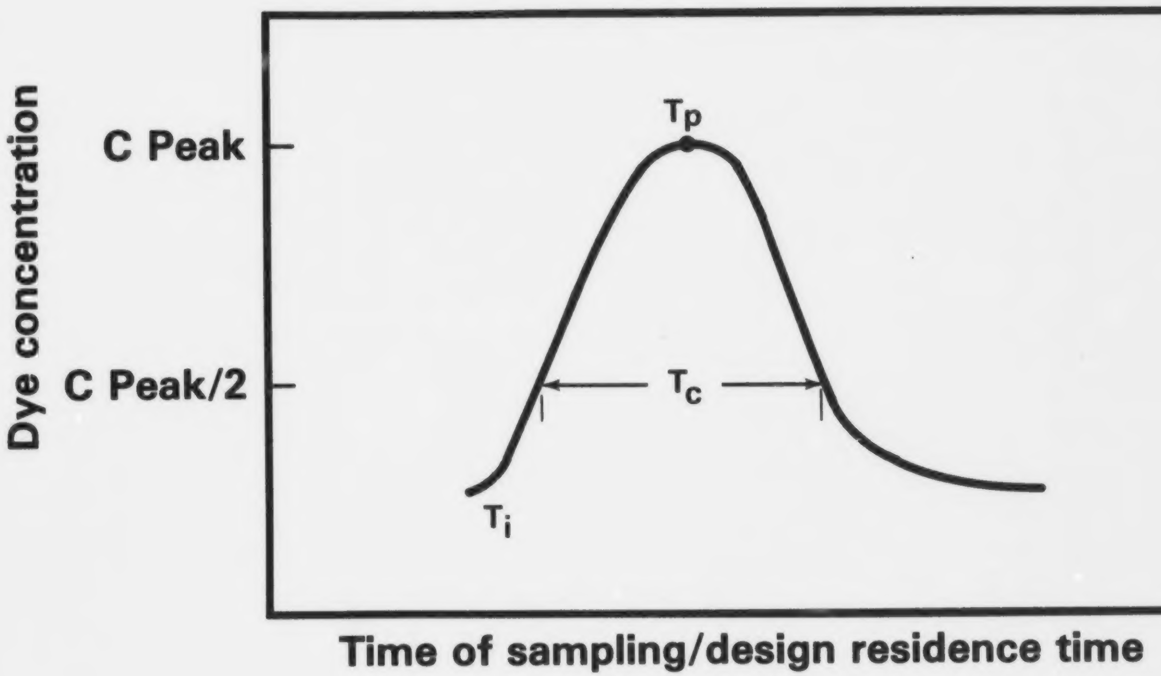


Table 19. REDUCED TIME VARIABLES FOR FLOCCULATORS

Flocculator	Tp	Tc	Ti
No. 1	0.82	0.85	0.15
2	No Results		
3	0.50	0.65	0.15
4	0.45	0.60	0.15
5	0.65	0.85	0.15
6	0.50	0.75	0.15
7	0.65	0.85	0.25

effective tank volume. It usually varies in the range of 0.17 to 0.57. Tc is a measure of the curve at its 50 per cent level and reflects the extent of small-eddy mixing of the vessel.

Because of sampling point differences, the first four chambers should be compared by themselves and the last three should be compared by themselves, since these were sampled nearer the exit. Number one chamber contains the most significant differences of the dimensionless variable. The higher values of Tp and Tc for the first chamber (higher than for chambers three and four) indicate a longer residence time and more small-eddy mixing. Since there is no indication of very severe short circuiting, the extra blade in the flocculator of the first chamber must have increased the degree of mixing significantly. Since the values of Ti are approximately the same for all chambers, no single flocculator chamber short-circuits much more than the others.

The values of Tc and Tp are larger for the last three chambers probably because they were sampled nearer the exit than were the first four chambers. Even so, the Tp values, which are also an indication of average residence time, are low and indicate that the actual retention time is somewhat less than the design value.

The time of peak absorbances, which correspond to the average residence times of water in the combined chambers, are listed in Table 20. The average residence time of water in the combined chamber ranges from 22 to 27 minutes. Since residence time in the flocculators averages about 11 minutes, the residence time in the flotation zone is between 11 and 16 minutes which is about one-half the design value. No peak was observed in Chamber 1.

A profile of the degree of phase separation at various locations in the flotation chamber might provide useful information to explain the suspected hydraulic turbulence. The profile samples were drawn out from three different depths at three sites representing 20 per cent, 50 per cent, and 80 per cent of the distance through the flotation chamber. Samples were drawn out from 1 foot, 3 feet, and 6-7 feet below the surface; the total depth of the chamber is 9 feet. Sludge was detected at the 7-foot location in one chamber, and the sampling point was then moved up to 6 feet. Even though the water is nearly saturated with oxygen, the very top layer of the bottom sludge is anaerobic. The degree of phase separation

Table 20. PEAK DYE CONCENTRATION TIMES FOR THE ENTIRE UNIT

Chamber No.	Peak Time, Min
1	-
2	27
3	26
4	24
5	25
6	22
7	25

was determined from the average of six turbidity measurements at each depth at each location. The average test results are listed in Table 21.

The relatively uniform improvement in turbidity as the water progresses through the chamber indicates the absence of severe mixing currents.

Overflow Rate Tests

Flow rate to one chamber was reduced from the normal 3,000 gpm to about 1,000 gpm with a flow-restricting weir cap. The lower rate increased the flocculator residence time from 18 minutes to about 54 minutes and the flotation chamber residence time from 19.5 minutes to about 40 minutes. The overflow rate was reduced from 3.8 gpm/ft^2 to less than 1.8 gpm/ft^2. Although the Reynolds Number was reduced substantially, it was still well into the turbulent region. Reduction of turbidity was used as the measure of performance. Tests were conducted at a recycle saturation pressure of 50 psig and at recycle rates of 30 per cent and 80 per cent. The test data are summarized in Table 10 in Appendix A. The average test results for the test chamber and the remainder of the AFU are compared in Table 22.

The test data show that effluent quality is not improved solely by a drastic reduction in overflow rate and increase in residence time. However, quality is improved substantially at the very high recycle rate. The turbidity reduction achieved by the test chamber at 80 per cent recycle approaches the performance of the pilot unit at pilot unit design conditions. Upon inspection, these data support the conclusion from Tables 5 and 6 that 25-30 per cent recycle (800 gpm) is optimum; in this test the 80 per cent recycle is 800 gpm. Thus, inclusion of these data into the data base indicates that the principle design parameter should be ft^3 flotation air released/ft^2 surface area. The per cent recycle can be misleading and is just a means to achieve the principle design parameter.

Reynolds Number Effect

The Reynolds Number in the flotation chambers normally exceed 80,000. This hydraulic variable cannot be readily changed because it is dependent on the physical dimensions of the chamber. The

Table 21. PERCENTAGE TURBIDITY REMOVAL AS FUNCTION OF DEPTH AND DISTANCE THROUGH FLOTATION CHAMBER

Depth, Ft	Per Cent of Turbidity Ultimately Removed at Indicated Distance Through Chamber 20%	50%	80%
1	67	71	90
4	80	77	94
6	87	96	100

Table 22. EFFECT OF THROUGHPUT ON TURBIDITY REDUCTION AT SATURATION PRESSURE OF 50 PSIG

Test No.	Feed Turb.	Effluent Turbidities and % Reductions[a]					
		Test Chamber--1,000 gpm Throughput				AFU	
		800 gpm Recycle		300 gpm Recycle		Norm. Condition	
		Turb.	% Red.	Turb.	% Red.	Turb.	% Red.
1	71	9	87	-	-	18	74
2	63	-	-	15	76	16	74

[a] (Normal Condition--3,000 gpm/Chamber Plus 800 gpm Recycle)

range over which it can be tested is too limited for any meaningful evaluation. Since Reynolds Number is dependent on the hydraulic radius as well as on linear velocity, a small test chamber with a substantially smaller hydraulic radius was constructed and was placed inside one of the flotation chambers. The test chamber consisted of a pair of 20 feet by 8 feet panels spaced at 8 inches. The smaller hydraulic radius of the test chamber reduced the Reynolds Number within the panel section to about 5,400. The inlet end of the panel section was positioned about 5 feet downstream of the recycle header. Samples for turbidity measurements were taken at various depths at the outlet end of the panel section and from similar points in the air flotation chamber proper. The test data are listed in Table 11 in Appendix A.

An examination of the data indicates that a Reynolds Number of 5,400 does not produce a significantly less turbid effluent than does a Reynolds Number of 80,000. These results corroborate the pilot plant data shown in Figure 18. In addition, in just a short period of time, the walls of the test chamber developed a prolific growth of slimes which tended to slough off and contribute to the suspended solids content.

SECTION 9

EVALUATION OF AIR FLOTATION UNIT PERFORMANCE

The overall performance of the AFU is measured by the percentage removal of contaminants as determined by analyses of daily, continuous composite samples. The sampler is described in Appendix B. Effluent samples were obtained from the API separator, the bio-flotation pond, and the air flotation unit. The following analyses were performed on each sample in accordance with the test methods listed in Appendix E.

Oil by Infrared Absorption, I.R. Oil

Oil by Hexane Extraction, APHA Oil (API Sep. Omitted)

Ammonia-Nitrogen by Nesslerization

Phenolics by Aminoantipyrine Method

Biochemical Oxygen Demand, 5 Day

Chemical Oxygen Demand--(One Per Week) Dichromate

Total Oxygen Demand--Ionics, Incorporated, Instrument

pH

Threshold Odor Number

Total Suspended Solids

Volatile Suspended Solids (One Per Week)

Phosphate--Stannous Chloride Method

Jackson Turbidity (API Separator Omitted)

Sulfonates (AFU Only)--Methylene Blue Method

The analytical data with daily flow rates and chemical dosages for each month from February, 1971, through February, 1972, are listed in Appendix C, Table 1 through Table 42.

The measure of unit performance is how much each of these contaminant parameters is reduced as the process water flows through the treating facilities, or the approach of the contaminant level to Indiana Stream Pollution Control Board goals.

All the quality parameters with the exception of ammonia-nitrogen are improved. The quality improvement, relative to removal of critical contaminants: APHA oil, total suspended solids, BOD, TON, and phenolics, is illustrated in Figures 23 and 24 for the six-month period, February-July, 1971, during which time most of this investigation was conducted. The monthly average percentage reductions across the AFU are plotted chronologically. The height of the bar shows the percentage reduction, and the number above the bar is the concentration of the contaminant in mg/l in the effluent. The solid line represents bioflotation performance and the dotted line, the AFU performance. Although the data are shown together for visual comparison, the AFU data will be discussed separately from the bioflotation data.

Performance is also measured by the approach to the goals established for effluent water quality from early pilot plant work. The important contaminant parameters include: APHA oil content, total suspended solids, BOD, phenolics, total phosphate, and threshold odor number (TON).

Although the goals have been approached for extended periods of time, the large-scale air flotation unit does not perform as well as had been expected based on the results obtained on the air flotation pilot unit. The poorer performance of the large unit is believed to be partly the result of high Reynolds Number turbulence that was not present in the small unit. The small unit operated at a Reynolds Number of about 1,500-2,000, while the large unit operates at a Reynolds Number in excess of 80,000.

Figure 23

Quality improvement of process water

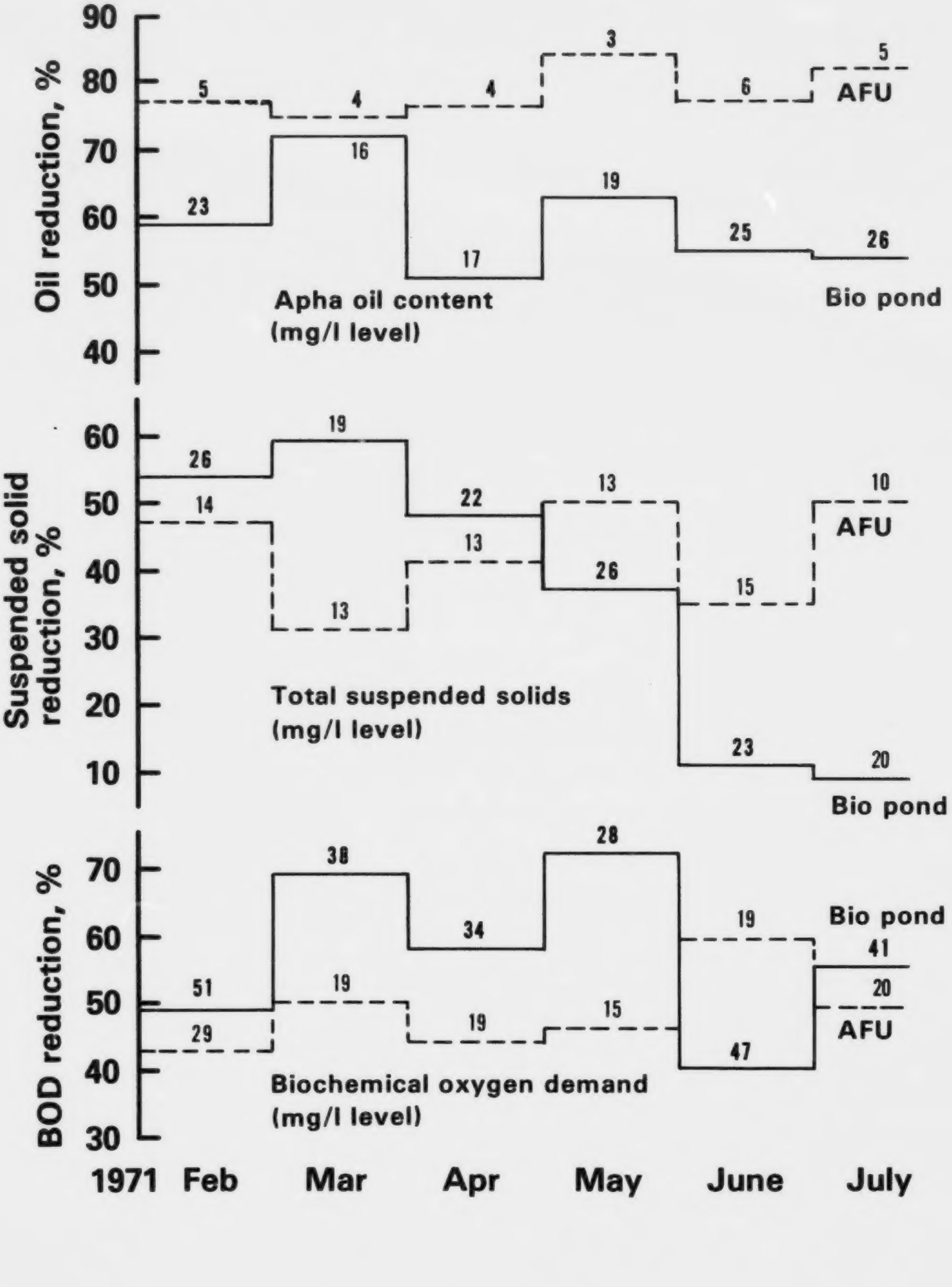
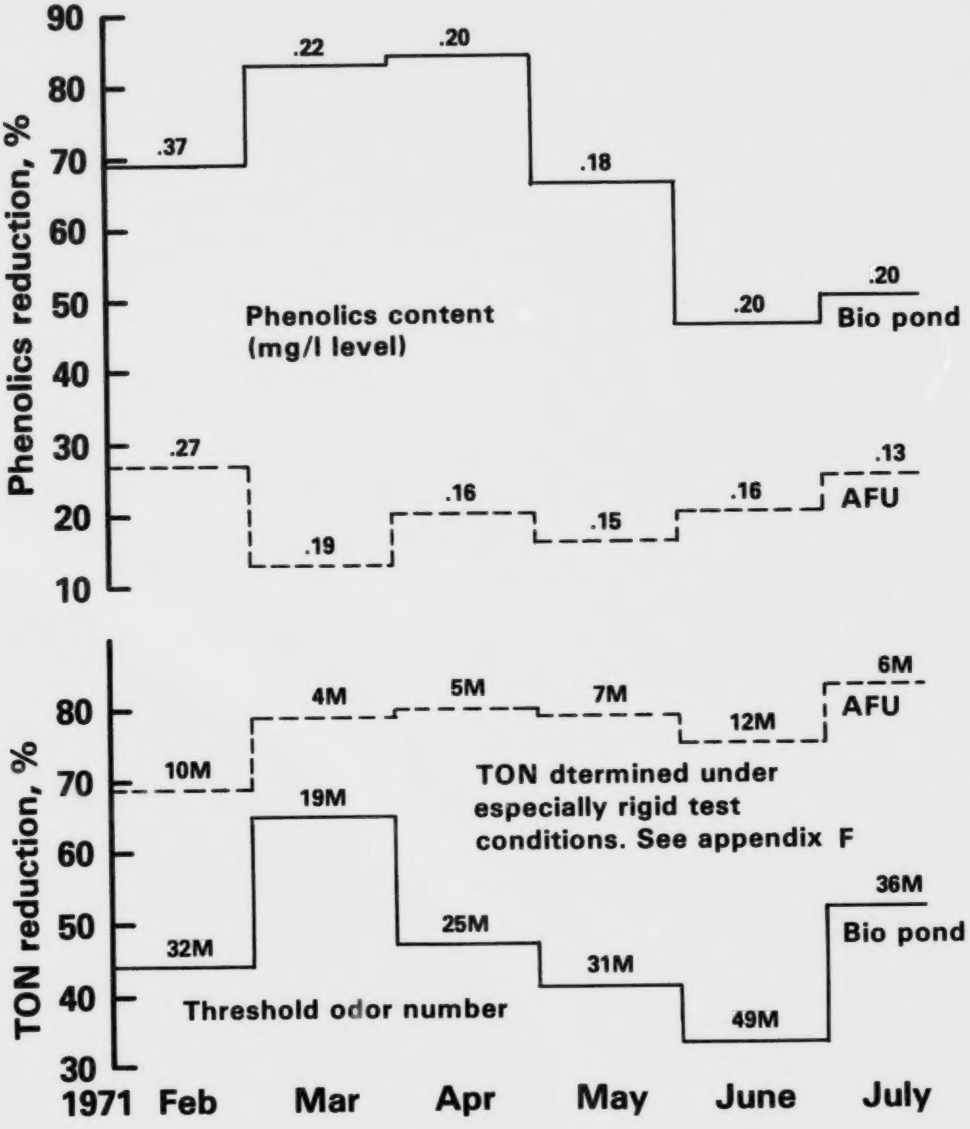


Figure 24

Quality improvement of process water



OIL REMOVAL

Although the pilot plant experience indicated that the air flotation process would remove some of the dissolved oil, and that APHA oil contents as low as 1 mg/l might be attainable, the large unit has never shown this very high degree of performance. A detailed examination of the daily analyses reveals that the minimum attainable APHA oil content of the effluent from the large unit is about 1.5 mg/l.

SUSPENDED SOLIDS REMOVAL

For removal of total suspended solids, the large unit does not perform as well as the pilot unit indicated. The typical effluent contains 13 mg/l suspended solids compared to less than 10 mg/l in earlier pilot plant work.

BOD REMOVAL

While the pilot plant showed removal of about 65 per cent of the BOD, the full-scale unit shows much smaller reductions. However, the absolute value of BOD in the effluent is usually less than 20 mg/l.

PHENOLICS REMOVAL

Although the percentage removal of phenolics in the AFU is small, the concentration of phenolics in the effluent is low; the monthly average data range from 0.15 mg/l to 0.27 mg/l. Most of the phenolics are removed in the preceding bioflotation unit.

PHOSPHATES REMOVAL

Because the phosphates react with alum to form an insoluble aluminum phosphate, phosphate content of the AFU effluent is always low; the monthly average data ranged from 0.05 mg/l to 0.10 mg/l. Phosphate removal was a key objective desired by the State of Indiana.

THRESHOLD ODOR NUMBER (TON) REMOVAL

Pilot plant studies indicated that TON removal should be typically better than 80 per cent. The monthly average TON data has ranged from 70 per cent to 80 per cent removal, approaching expectations.

TOD AND COD REMOVAL

Both total oxygen demand (TOD) and chemical oxygen demand (COD) are reduced with the same degree of efficiency as BOD; values near 50 per cent removal are typical. This compares rather favorably with the pilot plant results.

SCUM RECOVERY

The volume of scum recovery is highly variable. The volume is dependent on the oil and solids recovery, the alum dosage, and the amount of entrained water. Water content can range from 85 per cent to 95 per cent.

SCUM DISPOSAL

Although the AFU skimmings are presently being disposed of by a land-spreading operation, ultimately they will be incinerated in a fluidized-bed unit. When the incinerator route is considered, the water content of the skimmings is of immediate concern because of its effect on the incinerator fuel balance.

As mentioned earlier, a small change in the percentage water content amounts to a large, absolute amount of water. This quantity of water will have obvious effects on size of the fluid bed incinerator as well as the supplemental fuel requirements. In addition, facilities for adjusting the moisture content of the skimmings to some constant level should provide conditions for more stable incinerator operations.

Research department studies have shown that centrifugation is the best process for dewatering skimmings; it is simpler and requires less capital investment than pressure filtration, the other most likely process. The results of the centrifuge study are reported in detail in Appendix D.

The study showed that the water content of the AFU skimmings can be markedly reduced in a basket-type centrifuge with the aid of a coagulating polymer:

1. The volume reduction effected by the centrifuge varies inversely with the water content of the skimmings. During the test period, volume reductions ranged from 50 per cent to 80 per cent.

2. Solids recovery, oil recovery, and cake content can be maintained relatively constant by adjusting the centrifuge time cycle (feed time vs. cake removal time) to compensate for changes in water content of the skimmings. During the test period, averages achieved were: (1) solids recovery 95 per cent, (2) oil recovery 88 per cent, and (3) cake water content 75 per cent.

3. Cake heating value can be maintained relatively constant by controlling the water content of the cake, but some variations can be expected due to changes in the ratio of oil to solids in the skimmings. During the test period, calculated cake heating values of 3,000 BTU/lb were achieved.

REGRESSION ANALYSIS OF AFU DATA

The daily composite sample data for March, April, and May, 1971, were processed with a multiple regression program to determine the correlation coefficients for 11 independent variables. The dependent variables were:

1. Total Suspended Solids (TSS), mg/l, in AFU effluent
2. I.R. oil content, mg/l, of AFU effluent

The independent variables were:

1. I.R. oil content, mg/l, of the biopond effluent
2. NH_3 content, mg/l, of the biopond effluent
3. Phenol content, mg/l, of the biopond effluent
4. TOD, mg/l, of the biopond effluent
5. pH of the biopond effluent
6. TSS content, mg/l, of the biopond effluent
7. Phosphate, mg/l, of the biopond effluent
8. Sulfonate, mg/l, of the biopond effluent

9. Alum dosage

10. Polyelectrolyte dosage

11. Flow rate of effluent to lake, million gals/day

The linear correlations were poor. The sum of the R square values (correlation coefficient) was 0.22 for the TSS correlation. A perfect linear correlation would have an R square value of 1.0. A value of 0.8 would be considered fair-good. The correlation coefficient for the I.R. oil content of the product was somewhat better, R square = 0.44, but still poor. Here the least significant variables were TOD of feed, PO_4 of feed, alum dosage, and surprisingly, the sulfonate content of feed. A run dropping out these variables showed no improvement in the R square value. An attempt to improve the R square value by utilizing an exponential transformation was unsuccessful.

SECTION 10

BIOFLOTATION PROCESS

Effluent from an API separator contains a significant fraction of contaminants consisting of suspended matter and colloidally dispersed materials that will flocculate under certain conditions. Biological organisms have surface properties that accomplish this flocculation, and in conventional systems, the organisms complete the purification job by biochemically oxidizing the soluble materials. The bioflotation process provides a means for biochemically flocculating these solids and removing the flocculated solids physically in a concentrated form. This not only decreases treatment costs because the comparatively expensive process of biochemically oxidizing the flocculated material is avoided by its physical removal, but also improves the quality of the water. Extensive pilot plant work has demonstrated that continuous removal of the bioflocculated material results in a significant increase in the degree of purification attained by the bioflotation process. The threshold odor number, TON, was especially aided by the continuous physical removal of the bioflocculated material.

The means developed for concentration and removal of the bioflocculated material consist of a combination of brush aerator/booms/drum skimmers arranged as shown in Figures 25 and 26. The brush aerator provides for (1) oxygenation, (2) mixing, (3) fine bubbles for air flotation of the bioflocculated material, and (4) imparting a velocity vector to the surface water mixture. The booms (1) contain the air-floated solids, (2) direct the contained solids to the rotating drum skimming device, (3) define the boundary of the system such that the surface velocity is adequate for directing the air-floated solids to the drum skimmer, and (4) direct surface currents to provide enough hydraulic pressure at the drum skimmer such that any large size accretions of air-floated solids are deformed and pushed against the surface of the drum which facilitates the skimming efficiency of the drum in this service. The roller drum

Figure 25

Typical arrangement of brush aerators and boom/drum skimmers

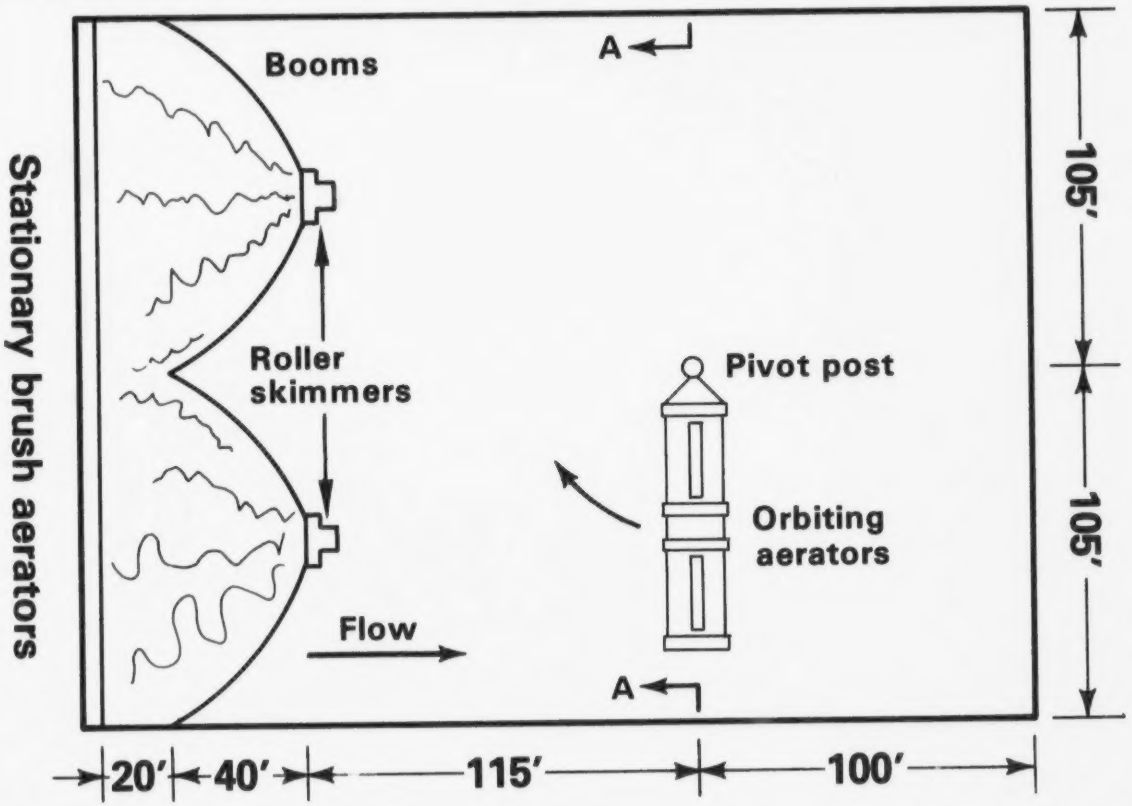
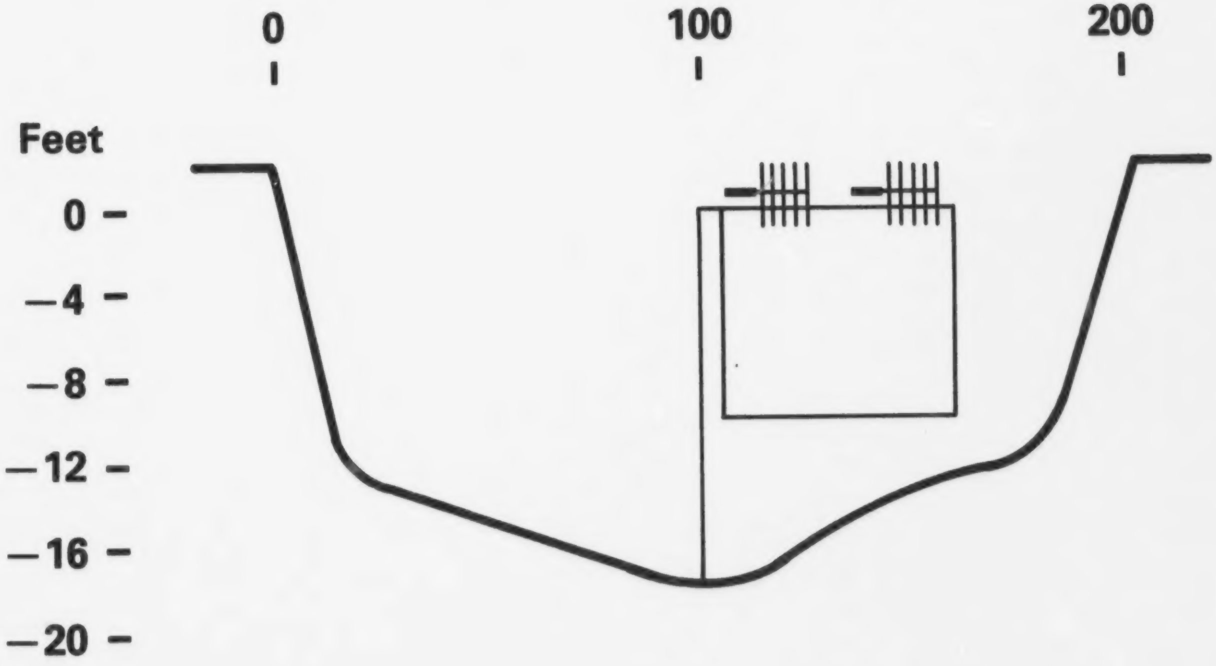

Booms
A
Roller skimmers
Pivot post
Orbiting aerators
Flow
A
Stationary brush aerators
105′
105′
20′
40′
115′
100′

Figure 26

Zone I bottom contour and orbiting aerator elevation, flow toward observer.


0
100
200
Feet
0 -
—4 -
—8 -
—12 -
—16 -
—20 -

Section A-A on Figure 25

skimmers provide (1) a means for removing the air-floated bioflocculated material continuously with limited operating attention and (2) for removal of the surface material in a dewatered, prethickened state. The optimum distance between the brush aerators and the roller skimmer drum was about 60 feet as determined by observations of solids capture and efficiency of skimming by the roller drum skimmers.

The bioflotation pond occupies an area of about six acres and is divided into five, roughly equal area zones as shown in Figure 27. The average depth throughout is fourteen feet. The pond holds 27 million gallons and provides a theoretical retention time of about 22 hours at the typical flow rate of 30 MGD. This pond provides a biological treatment of the process water from the API separator.

Prior to the installation of the orbiting aerator, the aeration facilities included four rows of fixed brush aerators drawing a total of 480 horsepower and four 20 hp floating turbine aerators in Zone II. In addition to being short of enough oxygen to satisfy the demand, the biopond compartments gradually filled with sludge, which required expensive dredging operations to remove. The sludge banks, composed of inert solids and biological material, reduced retention time, oxidation efficiency, promoted anaerobic activity with the release of partial decomposition products, and increased the threshold odor number of the process water effluent.

The experimental orbiting aerator installation, a pair of 50 hp brush-type aerators, appeared to offer a unique solution to the problem of inadequate oxygen supply and sludge deposition. The two, 25-foot, orbiting aerators are connected in tandem and turn around a pivot post such that all the circumscribed bottom areas of the basin are repeatedly subjected to currents sufficient to scour bottom sludge deposits as shown in Figure 28.

The bypass baffle can be adjusted to direct the hydraulic turbulence toward the lagoon bottom and assure reaeration and scouring of the sludge to an equilibrium level.

The orbiting aerator design provides a confined turbulent area to increase oxygen transfer capacity.

Figure 27

Plan view of bio flotation pond

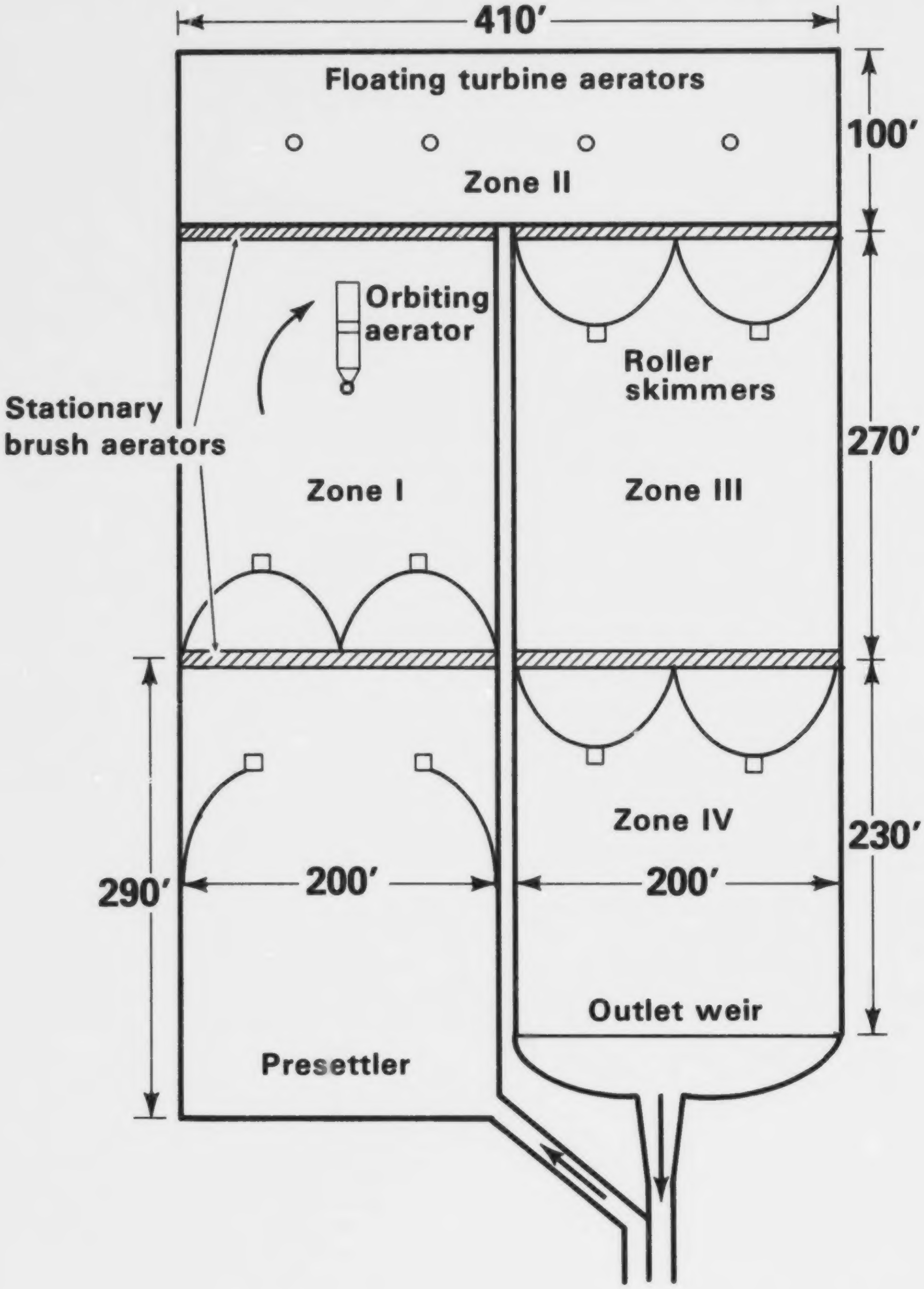
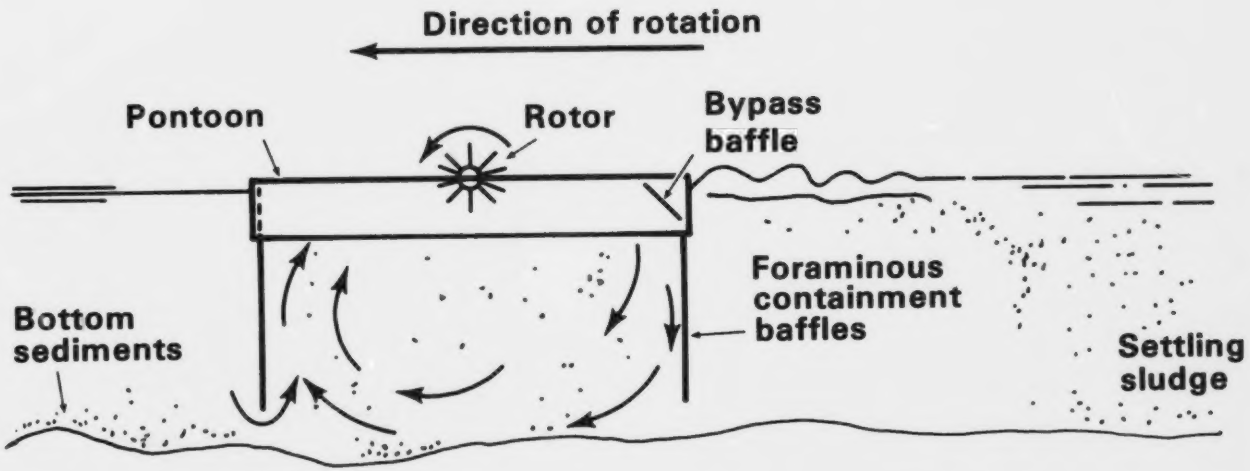

410′
Floating turbine aerators
100′
Zone II
Orbiting aerator
Roller skimmers
Stationary brush aerators
270′
Zone I
Zone III
Zone IV
230′
290′
200′
200′
Outlet weir
Presettler

Figure 28

Orbiting aerator in action, end view


Direction of rotation
Pontoon
Rotor
Bypass baffle
Foraminous containment baffles
Bottom sediments
Settling sludge

It further appeared that the bypass baffle could be adjusted to control the inventory of biological solids for optimizing biochemical oxidation in a manner analogous to batch treatment. The pond area in the path of the approaching orbiting aerator contains bottom sludge deposits, or the seed-activated sludge. As the aerator passes over this sludge, the bottom sediments are suspended, aerated, and mixed with the water. Finally, the aerated mixture would be ejected from the confines of orbiting aerator and undergo gravity sedimentation with some of the sludge being redeposited thus maintaining an equilibrium layer of active biological material.

The orbiting aerator in actual operation had a number of mechanical problems that precluded any test work involving the adjustable bypass baffle. These problems are detailed in Section XII. The inboard rotor turns at 65 rpm, while the outboard rotor turns at 70 rpm. The orbital rate is widely adjustable depending on the position of the bypass baffle and the wind velocity. All the evaluation work was done with the bypass baffle in the minimum drag position.

The boom/drum skimmer system consists of eight roller skimmers connected as shown in Figure 25 and Figure 27. These pontoon-mounted drums are 24 inches in diameter and 4 feet long, and the drums rotate in the direction of flow at the contact with water. The steel drums rotate at a rate of 12 rpm which is equivalent to a peripheral speed of 1.2 fps. One unit has a sponge-type drum surface and is used for skimming in the presettler zone.

The boom arrangement is "double V" with two roller skimmers in three of the four aeration zones. The drums are located 60 feet from the aeration brushes. The boom skirt is immersed to a depth of 24 inches.

A screw-type positive displacement pump on each unit pumps the skimmings into a collection manifold to an emulsion-treating tank along with skimmings from the API separator.

These units, like the orbiting aerator have experienced numerous mechanical problems which are discussed in Section XII.

SECTION 11

EVALUATION OF BIOFLOTATION UNIT PERFORMANCE

Evaluation of the bioflotation unit consists of separate evaluations of the orbiting aerator and the roller skimmers and an analysis of the overall performance efficiency in regard to removal of contaminants.

ORBITING AERATOR EVALUATION

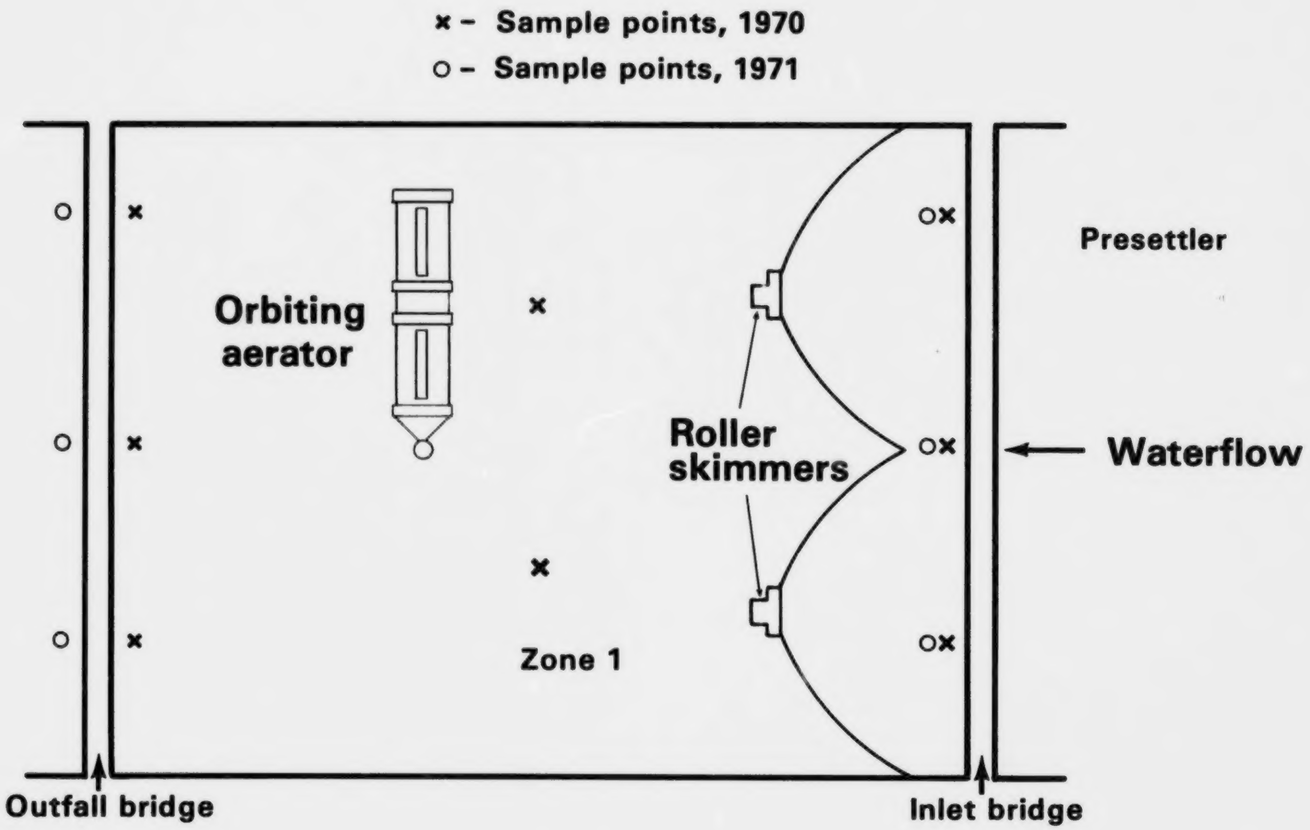
The mechanical performance record of the orbiting aerator has been very poor. The unit has been frequently out of service for many reasons which can be broadly classified as: motor failures, gear box failures, shaft failures, and power problems. While this idea of an orbiting rotary aerator may be a good one, this special type of application requires a more rugged mechanical design than engineered by the vendor.

Two types of tests were performed: one was to determine the effectiveness of this aerator to maintain solids in suspension and the other to measure the oxygen transfer capability.

The difference in total suspended solids content of the water entering and leaving the zone containing the orbiting aerator should be a measure of one of the objectives. Such samples were analyzed during three different time periods: summer of 1970, summer of 1971, and late winter of 1972. The 1971 samplings represented conditions immediately after the aerator had been returned to service following a six-month period of idleness while awaiting new motors. The 1970 samples were taken at eight locations in the zone as shown in Figure 29, three points each at the inlet and outlet of the zone, and two points in the path of the orbiting aerator. Samples were taken at depths of 1 and 6 feet.

Figure 29

Solids survey sample points


× – Sample points, 1970
○ – Sample points, 1971
Orbiting aerator
Roller skimmers
Presettler
Waterflow
Zone 1
Outfall bridge
Inlet bridge

The 1971 and 1972 samples were obtained only at the one-foot level at inlet to Zone I and at the inlet to Zone II. Inlet to the zone means that the samples were taken immediately downstream of the aeration brushes at the inlet to each zone. The average suspended solids data are listed in Table 23.

The test data are in conflict and may reflect sampling problems that cannot be compensated for. The two early sets show an increase in total suspended solids and suggest that the aerator is scouring the bottom of the pond and suspending some of the sludge. The more recent data show no change in the level of suspended solids and correspond to the results obtained during a period when the orbiting aerator was not operating.

Another measure of aerator performance is its effect on the level of bottom sludge in Zone I. Soundings were performed during the month of June, 1971. Sludge depth was measured transverse to flow at several locations: at 50 feet, 80 feet, 170 feet, and 260 feet from the inlet end of Zone I. The pivot post for the orbiting aerator is located at the 170-foot point. The sludge data are summarized in Table 24.

The lower level of sludge downstream of the rotor suggests that it can maintain a low sludge level.

Oxygen Transfer

Dissolved oxygen and total oxygen demand (Ionics instrument) measurements were made at the 1- and 6-foot levels at the inlet and outer outlet of Zone I to determine oxygen transfer rates. A Weston and Stack portable analyzer was used for this study. Immediate dissolved oxygen demand measurements (IDOD) by ASTM procedures were made at the one-foot level at each of these locations. The test results are listed in Table 25.

The data are widely variable and conflicting and are not meaningful. This is to be expected because the theoretical aeration capacity of this unit, at a process water flow rate of 30 MGD, is of the order of 20-25 mg/l. With TOD values of 500-700 mg/l, this small amount is easily lost in sampling and analytical variations.

Table 23. ORBITING AERATOR SUSPENDED SOLIDS DATA

	Total Suspended Solids, mg/l		
Test (Surveys)	Into Zone I	Under Aerator	Outlet Zone II
1970 (Average of 3)	26	37	34
1971 (Average of 6)	26	-	35
1972 (Average of 3)	47		45
Orbiting Aerator			
1970 (Average of 3)	33	-	

Table 24. DEPTH OF SLUDGE IN ZONE I OF BIOFLOTATION POND

Distance From Inlet, Ft	Sludge Depth, Feet	
	Range	Average
50	2 - 8	4
80	3 - 6	5
170 (Under Orbiting Aerator)	0 - 5	2
260	1 - 3	2

Table 25. OXYGEN SURVEY DATA

	Zone I Inlet, mg/l					Zone I Outlet, mg/l				
	D.O.		TOD		IDOD	D.O.		TOD		IDOD
Test	1'	6'	1'	6'	1'	6'	1'	6'	1'	6'
1	1.8	0.5	433	390	3.0	0.04	0.03	338	473	2.6
2	2.2	0.2	496	518	6.0	0.03	0.02	523	683	2.5
3	2.6	1.3	645	630	1.4	0.04	0.04	575	638	1.4

(Aerator Off in Test 3)

Additional samples were taken for immediate oxygen demand (IDOD) measurements during April, 1971. One set of data was obtained with the orbiting aerator not operating and three sets with it operating. The test results are summarized in Table 26.

The higher IDOD at the outlet indicates the increased presence of acclimated microorganisms and complicated oxidation reactions. The technique of using the difference in IDOD to measure or to estimate oxygen transfer rates has not been used successfully by us in aerated lagoon systems.

Dissolved Oxygen Survey

A dissolved oxygen survey was made across the bioflotation pond, the air flotation unit, and into the lake in July, 1971, and again in April, 1972. The oxygen data were obtained at two locations at the inlet and outlet of each zone of the bioflotation pond and 1- and 3-foot levels. The data for the two locations were averaged and are reported as a single result. Dissolved oxygen data were also obtained in July, 1971, in the bioflotation pond effluent channel through the air flotation unit and into the lake. The data are listed in Table 27.

ROLLER SKIMMER PERFORMANCE

The many mechanical ills suffered by the roller skimmers which are detailed in Appendix F have been largely overcome. The operating factor for these devices has been improved from less than 50 per cent to more than 80 per cent by the substitution of a cellar-type sump pump for the screw-type positive displacement pump. These units still freeze when air temperature drops below + 10° F.

Performance tests were conducted on a skimmer in Zone I and in Zone IV. Since there is more oil on the surface of the pond in Zone I than there is in Zone IV, oil recoveries should be different.

Emulsion recoveries were measured on three occasions in Zone I and the emulsion analyzed for oil and solids. The data are listed in Table 28.

Table 26. IMMEDIATE OXYGEN DEMAND AROUND ZONE I, MG/L

Sample Point Location	Orbiting Aerator Inoperative		Orbiting Aerator Operating Average of Three	
	Inlet	Outlet	Inlet	Outlet
Right side	0	0	0.3	0.7
Center	0.25	0.75	0.1	0.5
Left side	0.5	0.75	0.3	0.5

Table 27. BIOFLOTATION UNIT OXYGEN SURVEY

	Orbiting Aerator Inoperative		Orbiting Aerator Operating	
	July, 1971		April, 1972	
Depth:	1'	3'	1'	3'
Location				
Presettler Outlet	0.15	0.10	0.20	0.40
Zone I Inlet	3.1	2.9	4.7	2.8
Outlet	0.21	0.14	0.09	0.03
Zone II Inlet	2.1	0.7	2.7	1.6
Outlet	0.20	0.17	0.2	0.2
Zone III Inlet	2.6	1.8	3.4	3.2
Outlet	(1)	-	-	-
Zone IV Inlet	3.3	2.3	2.8	2.8
Outlet	1.2	1.2	2.6	2.6

(1) Inaccessible

Table 28. EMULSION RECOVERIES BY A ROLLER SKIMMER IN ZONE I

Test	Emulsion Recovery	Soxhlet Analyses		
		Weight, %		
	gpd	Oil	Solids	Water
1	520	30.0	5.8	64.2
2	483	29.8	4.7	65.5
3	346	-	-	-

The daily oil recovery by this single unit is 100 to 150 gals per day and will vary depending on the quality of oil available to contact the skimmer.

A similar test on a Zone IV roller skimmer shows lower oil recovery from that zone, as would be expected. Although the emulsion recovery rate was about the same, the emulsion was essentially all water. The roller skimmer will remove emulsions from a liquid surface. If oil-solids are on the surface, it recovers them; if the surface is essentially clean, it picks up water. Recovery of oil by the drum surface requires contact between the oil and the drum. Strong winds can effectively isolate quantities of oil and prevent drum contact.

OVERALL PERFORMANCE OF THE BIOFLOTATION POND

Effectiveness of the bioflotation pond is measured by how well it reduces the concentration of critical contaminants. The percentage reduction of APHA oil, total suspended solids, BOD, phenolics, TON, and TOD are plotted chronologically in Figure 23 and Figure 24 with similar data from the AFU. The APHA oil data for the biopond feed were obtained from unreported I.R. oil analyses by way of an APHA oil--I.R. oil correlation. The height of the solid line shows the percentage reduction, and the numbers show the mg/l of the contaminant in the biopond effluent.

APHA Oil Removal

Oil removal in the biopond ranged from 51 to 72 per cent between February and July. Efficiency of removal might be influenced by the number of roller skimmers in operation. However, an examination of roller skimmer operating factor, listed in Table 29, relative to percentage reductions shows no clear-cut relationship.

Other factors that can influence the oil reduction are the degree of emulsification, the wind, and oil settled to the bottom with sludge.

Total Suspended Solids (TSS)

The percentage reduction of TSS is not a meaningful measurement of performance because the BFU is biologically active. While the TSS in the influent is presumably inert material and might settle out, the organisms generated in the BFU are being washed out in the effluent.

Table 29. ROLLER SKIMMER OPERATING FACTORS

	O.F., %	% Oil Reduction
February	46	59
March	62	72
April	48	51
May	93	63
June	80	46
July	61	54

Ideally, all the solids in the influent should remain in suspension to be recovered in the air flotation unit.

Biochemical Oxygen Demand (BOD)

The percentage removal of BOD ranged from about 40 per cent to 70 per cent during the six-month evaluation period. As would be expected, the changes in BOD content varied directly with the changes in percentage oil removal.

Phenolics

The percentage reduction in phenolics content ranged from 45 to 84 per cent. The low percentage reduction relates to a relatively low phenolic content in the feed. Phenolics concentration across the biopond tends to asymtotically approach a minimum value of 0.15 mg/l in the effluent.

Threshold Odor Number

The TON reduction across the biopond ranged from 34 to 65 per cent.

SECTION 12

MECHANICAL PROBLEMS WITH EQUIPMENT

ORBITING AERATOR

The mechanical problems with the orbiting aerator have been numerous and began soon after its installation late in 1969. The cure of a specific problem has sometimes been slow, because the primary cause of the problem was not immediately determined or replacement parts were not readily available. The aerator is difficult to service because of its remote location and the large size of some of the components. The problems involved misaligned couplings, belt drives, and motors. In some cases, the problems were related to poor design while others reflect poor workmanship. The first problem involved a coupling.

The coupling on the shaft of the gear reducer of the inboard rotor walked off the shaft. The first corrective action involved drilling and tapping the shaft to secure the key holding of the coupling. This action was inadequate. Detailed investigation revealed that the stop plate on the coupling and gear-reducer shaft had not been installed on the purchased equipment. Installation of a new shaft with a stop plate and a new press-fit coupling solved the walking problem.

In June, 1970, the speed-reducer coupling began to wobble because of misalignment.

During the summer, there were many overloads that tripped out the circuit breakers. Investigation revealed that the inboard 40 hp motor was overloaded. Because the tandem combination of aerators revolves in a circular orbit, the inboard rotor should rotate at a lower rpm than the outboard rotor. At equal rpm, the inboard rotor dissipates additional energy into churning of the water. At equal speeds, the service factor for the inboard motor exceeded 1.15 while the design service factor was 0.9. Installation of a smaller sheave decreased rotor rpm from 70 down to 65. Although this has cured the problem, the motor service factor is 1.0 and provides no allowance for prolonged overloading.

In October, 1970, the three belts transferring power to the gear reducer began to slip. This short belt life is attributed to belt overloading. The three belts were renewed, but the recommended solution is to replace the three-belt drive with a four or five-belt drive.

A continuing problem involved all-too-frequent shorting out of the 40 hp motors (three times in four months). The motors are classified as drip-proof with encapsulated windings. This is not the proper motor design for this type of service. The atmosphere around the orbiting aerator is constantly a watery-oily mist generated by the action of the rotor. This mist is drawn through the motor windings, and some deposition occurs. The moist deposits form an electrical path and short out the motor. One motor has been rewound, while the other has been cleaned, dried, varnished, dried, and the opening epoxied. These motors failed again in January, 1971, at which time it was decided to replace them with 50 hp, totally enclosed, fan-cooled units. These new motors were installed late in June and failed after one week's operation. Failure was due to a factory defect in the insulation in both motors which caused them to short out. The orbiting aerator was returned to service early in August after a month of idleness while the motors were repaired.

During the month of July, the submarine power cable was replaced with an overhead cable because of evident leakage. Examination of the submarine cable revealed that the insulation was being attacked by the oil and sludge in the biopond.

ROLLER SKIMMERS

The roller skimmers have experienced numerous mechanical problems which have kept them out of service half of the time. Almost every element of the roller skimmer assembly has had some mechanical problems; the screw-type positive displacement pumps, the drive motors, the gear reducers, and the wiper blades. The pumps have had the greatest number of problems, many of which have been corrected, but others are not yet completely resolved. During the fourth quarter, at least one of the eight units was down all the time; and about 10 per cent of the time, four skimmers were down. Until we learn to cope with freezeups, cold weather operation, below 10^{o} F, will continue to be poor.

Within two months of initial installation, five of eight units had failures for: uneven rotor wear, hardening and crystallization of the Buna-N stators, and bearing failures. The cause was diagnosed to be improper pump speed. The pumps were run at 900 rpm instead of 300 rpm as the pump manufacturer recommended. New pump stands were installed.

Cold weather causes freezing problems which have been somewhat alleviated by the installation of heating tapes. Some freezing problems still occur. In spite of reducing pump rpm, failures continued at an epidemic rate. In January-February, 1970, there were four failures due to worn stators. Trouble was attributed to heat and chemical attack to the Buna-N linear. It was also thought to be caused by pumps running dry. The most probable cause for loss of prime was air inleakage through loose packing. Inleakage was overcome by reversing the direction of flow through the stators and, thus, putting a positive pressure on the bearing packing. At the same time, four stators with Viton-A liners claimed to have more resistance to heat, chemicals, and abrasion were ordered for evaluation. In November, 1970, one of the Buna-N pumps again failed and showed both stator and rotor wear. The worn parts were returned to the manufacturer for their study, and a Viton-A stator was installed. Because the pump problems are seemingly unending, the possibility of using an entirely different type of pump was considered.

In February, 1971, a new design sump pump was installed on the unit for evaluation. A vertical sump pump has given excellent service. This pump must still survive a winter season to rate as satisfactory.

Drive motors have shorted out a few times because of moisture getting into the windings. The motors had to be removed and dried out in an oven.

The drive sprockets on four gear reducers failed due to unusual wear in the hub. The cause was diagnosed to be a loose fit which permitted some movement between the shaft and the hub. The problem was corrected by tailoring the hub diameter to provide a tight press-fit on the shaft of the gear reducer.

In February, 1970, the ultra-ethylux wiper blades were found to be badly warped. These wiper blades had been installed without backup plates. The prototype unit had a Delrin wiper blade with a steel backup plate. Because the Delrin blade showed no signs of wear, Delrin with the backup plate was substituted on all seven roller skimmers.

CHEMICAL PUMPS

The alum addition pump, a diaphragm type controlled volume pump, is giving unsatisfactory service and is probably not suited to pumping 48 per cent solution of alum. The trace amounts of calcium sulfate contaminant tend to deposit in the orifices in the pump head and restrict the pumping action. The pump system has been replaced by a gravity feed system and a magnetic flow controller.

POLYELECTROLYTE PUMP

The polyelectrolyte positive displacement pump has had only minor problems associated with solids in the polyelectrolyte solution. The solids are mostly iron and are thought to be products of corrosion from the storage tank. As of this time, the problem is of minor consequence. Subsequently, progressing cavity (screw) pumps have given excellent service.

SECTION 13

OPERATING AND MAINTENANCE COSTS

The air flotation unit has its own cost center, and all charges were accumulated under that number. Both the orbiting aerator and roller skimmers are simply items of equipment operating in the water-treating facility, and the repair charges were accumulated in the API Separator cost center. For this report, the chargeable maintenance items were lifted out of the detailed listing of completed work orders. Undoubtedly, some repair items were missed in the search because the job order descriptions were not always definitive.

The cost information to date for Project DML-12050, including engineering and construction costs as well as operating costs, is listed in Table 30.

The listed operating costs do not reflect the entire costs for operating the bioflotation and air flotation combination. Routine attention to the aerators and skimmers on the bioflotation pond requires operator attention equal to one manshift per day and is not included in the listing. The air flotation unit requires the attention of two-thirds of a manshift per shift and is included along with supervision charges. The projected 1972 costs listed in Table 31 have been adjusted to include all the necessary operator attention, but excludes supervision charges.

The treating cost, based on the total annual cost of $816,400, will be about 7.5 cents per 1,000 gallons. Chemical costs are based on treating 30 mgd with 30 mg/l alum, 6 mg/l DMA/EPI cationic polyelectrolyte, and 0.3 mg/l anionic polyelectrolyte.

Table 30. COST INFORMATION

A. Construction

	Material and Labor by American	Material and Labor by Contract	Eng'd. & Overhead	Total
To Jan. 1, 1970	$357,882	$361,339	$138,168	$857,389
Jan. 1 to Dec. 31, 1970	24,479	86,296	20,757	131,532
Jan. 1, to June 30, 1971	948	-	2,233	3,181
Total	$383,309	$447,635	$161,158	$992,102

B. Operation

	Operation & Maintenance	Post Construction Studies and Reports	Total
To Jan. 1, 1970	$ 0	$ -	$ 0
Jan. 1 - Dec. 31, 1970	178,522	104,410	282,937
Jan. 1 - Dec. 31, 1971	245,367	100,000	345,367
Total	$423,889	$204,410	$628,299

Table 31. PROJECTED 1972 OPERATING AND MAINTENANCE COSTS FOR THE COMBINATION OF BIOFLOTATION AND AIR FLOTATION

Operating Item	Maintenance	Operating	Utilities	Total
Air Flotation Unit	$34,000	$ 30,800	$36,000	
Chemicals	-	350,000	-	
Roller Skimmers	6,500		1,200	
Orbiting Aerator	2,000	15,300	5,900	
Other Aeration Devices	10,000		33,000	
Total	$52,500	$396,100	$76,100(1)	$816,400

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(1) Based on cost of purchased power. Actual cost is less because internally generated by-product power is used.

SECTION 14

ADDENDUM

This addendum section reports work subsequent to 1972. Basic water chemistry was studied further, and principles were outlined which permitted the phase separation efficiency of the air flotation process to be optimized. Fundamentally, maximizing phase separation efficiency by the air flotation process required recognizing that an intrinsic property of solids in the presence of water is a negative electrical surface charge (zeta potential). Flotation air bubbles also have a negative zeta potential. The water/air interface has a negative charge in the absence of solutes and remains negative with inorganic and organic solutes typically encountered in waste waters. In the solute-free water, the charge is attributed to orientation of water dipoles resulting in a higher concentration of OH^- than H^+ on the water side of the interface. Maximizing air flotation phase separation efficiency requires that these coulombic, repulsive forces be controlled by controlling the properties of the dispersed phase. This involves developing practicable means to apply the Derjaguin, Landau, Verwey, and Overbeek (DLVO) theory of colloid stability. The availability of improved polyelectrolytes and zeta potential instrumentation simplified this problem.

AIR FLOTATION DEFINITION

A proper place to start a discussion of air flotation is a definition that recognizes the principle limitation of the process; it will not efficiently achieve the phase separation of negatively charged colloidal solids. The definition, therefore, should spell out the application more carefully than done heretofore:

> Dissolved air flotation may be defined as clarification of a suspension of flocculated material by contact with minute bubbles that attach to the solids constituting the suspension, causing the suspension to be separated from the clarified water by flotation.

This definition puts proper emphasis on the fact that the material being separated should not be colloidal with its inherent, high, repulsive, negative zeta potential required to maintain the colloidal state, but a flocculated suspension. A flocculated suspension implies a proper chemical pretreatment consistent with the needs of a colloidal system.

A flocculated suspension requirement also determines the design basis of the DAF unit; it shall have provisions for mixing chemicals, flocculating the destabilized suspension, a flotation zone for phase separation, and shall be the recycle air pressurization design. Dissolved air flotation designs using total, or partial, feed pressurization are not appropriate because any flocculation of the destabilized suspension achieved in a pressurization vessel is destroyed by the energy of the pressure drop across the back-pressure control valve.

PROPERTIES OF SUSPENDED SOLIDS

Refinery effluents from aerated lagoons are similar to surface waters, sanitary sewage, API separator effluents, fire and cooling water ponds, etc., in that the suspended materials usually are predominately colloidal or a combination of colloidal and very slightly flocculated suspensions. The stability of these colloidal systems relates to the fact that the individual particles carry like electrical charges, causing their mutual repulsion. Except for some isolated examples, the charge on organic, inorganic, and biocolloids are negative when suspended in water. Colloidal destabilization by chemical treatment has the objective of neutralizing, or reducing, the electrical charge so that mutual repulsion is reduced to the extent that individual particles can approach each other close enough for van der Waals and/or chemical forces to become effective. The attractive van der Waals forces cause the particles to aggregate into agglomerates, which facilitates their removal by sedimentation, air flotation, or filtration processes. The surface charge on colloidal particles may be estimated by electrophoretic, electroosmotic, streaming, and sedimentation potential techniques.

We have found that the electrophoretic procedures and equipment of Riddick[9] permits the rapid determination of colloidal charge to be made, and all our investigations involved use of the Zeta Meter. Accordingly, electrokinetic values reported herein are zeta potentials (ZP).

Electrokinetic Charge on Colloidal Particles

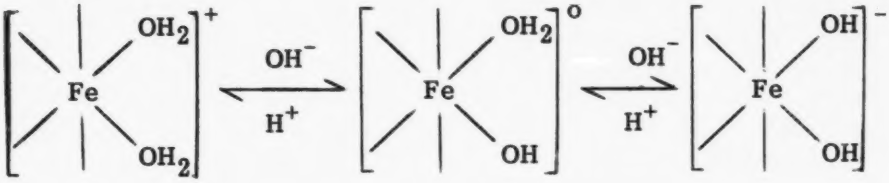
The efficiency of air flotation for phase removal depends on the state of subdivision of the suspended matter; higher capture and removal efficiencies are achieved with discrete particles of substantial size, and increasingly poorer efficiencies are observed with increasing colloidal solids fraction. Investigation indicated that the negatively charged flotation microbubble was repulsed by the negatively charged colloidal solids such that poor bubble adherence for flotation occurred. Consequently, the key to maximizing the effectiveness of the air flotation process was found to be essentially neutralizing, or reducing, the electrical charge of the colloidal particles to reduce coulombic repulsion due to like charges.

Microorganisms, dispersed oil colloids, and inert suspended matter, such as inorganic sulfides, silt, coke fines, etc., that are present in municipal sewage and refinery effluents, are negatively charged. The net electrokinetic charge; i.e., zeta potential, on colloidal particles is a result of (1) ionization, (2) ion adsorption, and (3) ion dissolution mechanisms.

The amino acids, proteins, and polysaccharides constituting the surface of biocolloids, for example, acquire their charge mainly through ionization of functional carboxyl and amino groups to give $-COO^-$ and $-NH_3^+$ ions. The degree of ionization of these functional groups, and thereby the net charge on the particle, depends on the pH of the solution. The pH at which the ZP is zero is called the isoelectric point; at a lower pH (more acidic), the ZP is positive; and at a higher pH (more alkaline), it is negative.

Solids dispersed in water typically have negatively charged surfaces, because cations have a greater tendency to become hydrated and reside in the aqueous solution than do anions, which are smaller, less hydrated, and more polarized, thereby having the greater tendency to be adsorbed. The net surface charge; i.e., ZP, may be acquired by the unequal adsorption of oppositely charged ions; however, ion adsorption may be positive or negative.

Ionic substances may acquire a surface charge, because the ions of which they are composed dissolve unequally in solution. In the case of the aluminum and iron primary coagulants, for example, hydrogen and hydroxyl ions are in equilibrium with the solid phase hydrous oxide. With excess hydrogen ions, the surface of the solid phase is positively charged; with excess hydroxyl ion, the surface is negatively charged. Since the concentrations of the hydrogen and hydroxide ions determine the charge at the particle surface, they are called potential determining ions. This concept may be illustrated as follows:



Electric Double Layer--

As early as 1879, Helmholtz[10] described the charge on colloidal surfaces in terms of an "electric double layer," and subsequently, Guoy and Chapman[11] described a diffuse, electric double-layer model that permitted more quantitative treatment of electrokinetic data. Verwey and Overbeek[12] set forth the classic work containing the mathematical foundation for showing that the tendency of fine particles to remain dispersed was due to the mutual repulsion of their electrical double layers being sufficient to overcome the van der Waals attractive forces pulling them together. The Russian investigators, Landau and Derjaguin, had much the same idea and published the electrical double-layer repulsion part in 1941. The total treatment is now known as the DLVO Theory.[13]

The electric double layer may be regarded as consisting of two regions: (a) an inner region which may include adsorbed ions, and (b) a diffuse region in which ions are distributed according to electrical forces and thermal motion.

Stern[14] proposed a model in which the boundary of the inner region (Stern layer) was located by a plane (the Stern plane) about a hydrated ion radius from the surface. Adsorbed ions attached to the surface by electrostatic and/or van der Waals forces may be dehydrated in the direction of the surface. A certain amount of solvent will also be bound to the charged surface in addition to the adsorbed ions. The shear plane, therefore, is probably located farther from the surface than the Stern plane. Ions with centers beyond the Stern plane are considered to be in the diffuse part of the double layer. These concepts are illustrated in Figure 30.

Electrokinetic potentials relate to the mobile part of the particle; therefore, the electrokinetic unit consists of the volume enclosed by the shear plane, which is rather inexactly known. The potential difference between the surface of shear and the solution is called the zeta potential (ZP).

DLVO THEORY

The DLVO Theory quantifies particle stability in terms of energy changes when particles approach one another. The total energy is determined by summation of the attraction (London-van der Waals forces) and repulsion (overlapping of electric double layers) energies in terms of interparticle distance. The general character of the resulting interaction energy-distance curve illustrates the very significant conclusions: (1) attraction will predominate at small and large distances, and (2) repulsion may predominate at intermediate distances depending on the actual values of the two forces. An important purpose of the chemicals used for destabilization is to reduce or eliminate the repulsion force at intermediate distances so that attractive forces will predominate and the particles will aggregate.

These principles are readily illustrated by the interaction energy curves in Figure 31. The energy of attraction curve (V_a) and the energy repulsion curve (V_r) are summed and yield the interaction energy curve (V_i). The interaction energy curve shows a repulsive energy maximum (V_m) which is an energy barrier to coagulation and the formation of stable aggregates of particles by attainment of interparticle distances which permit attractive forces at the primary minimum to react. This example illustrates another characteristic feature of these energy curves, and that is the existence of a secondary minimum at relatively large interparticle distances. If this secondary minimum is moderately strong, it can give rise to a loose, easily reversible form of flocculation. For small particles with a diameter less than about 200 A°, the secondary minimum cannot achieve this loose, reversible flocculation in those cases where the energy barrier (V_m) is large enough to prevent normal coagulation into the primary minimum. Thus, for complete destabilization of systems composed of fine particles, a chemical approach that responds to zeta potential charge neutralization is required.

Figure 30

Representation of electric double layer according to Stern's Theory

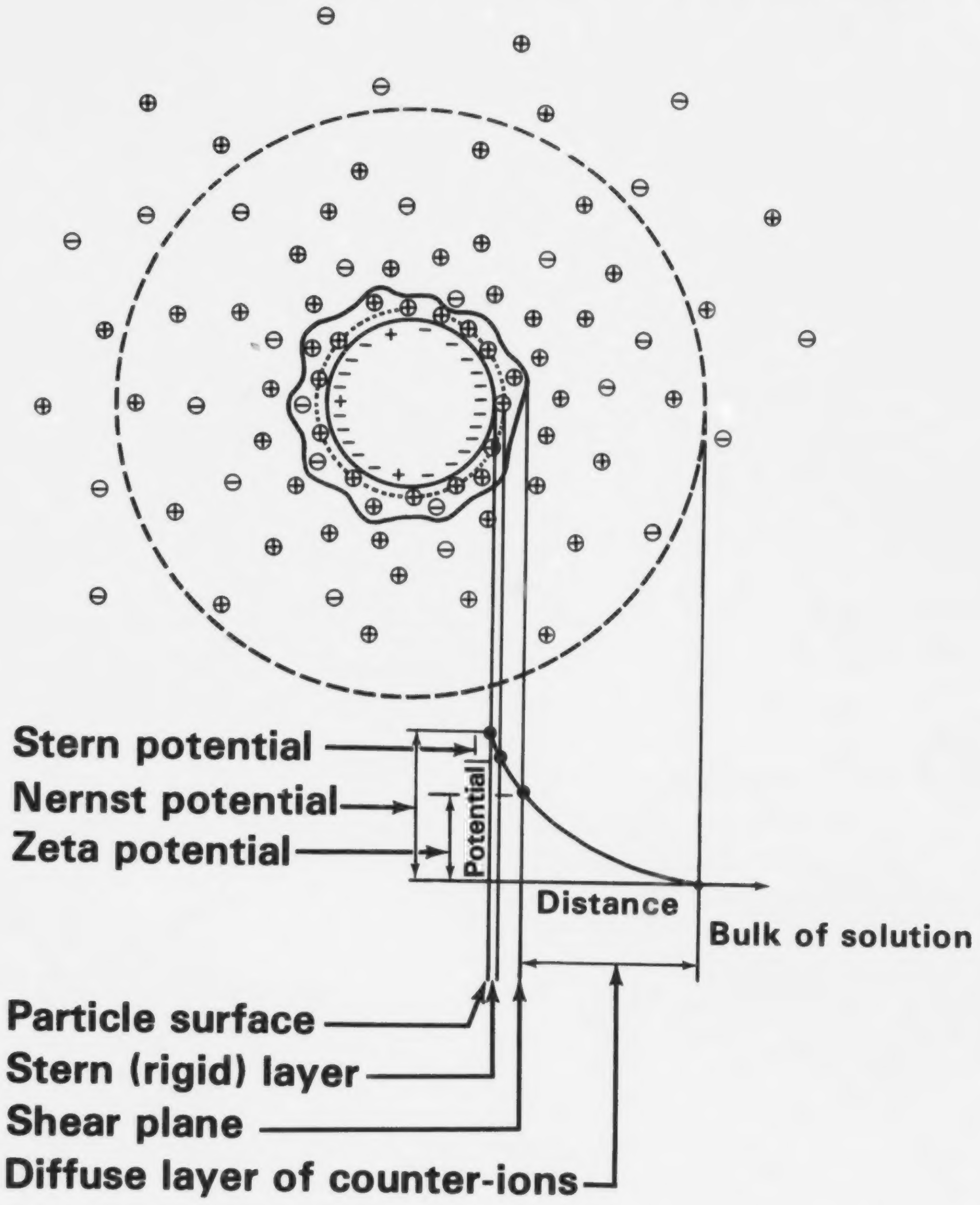
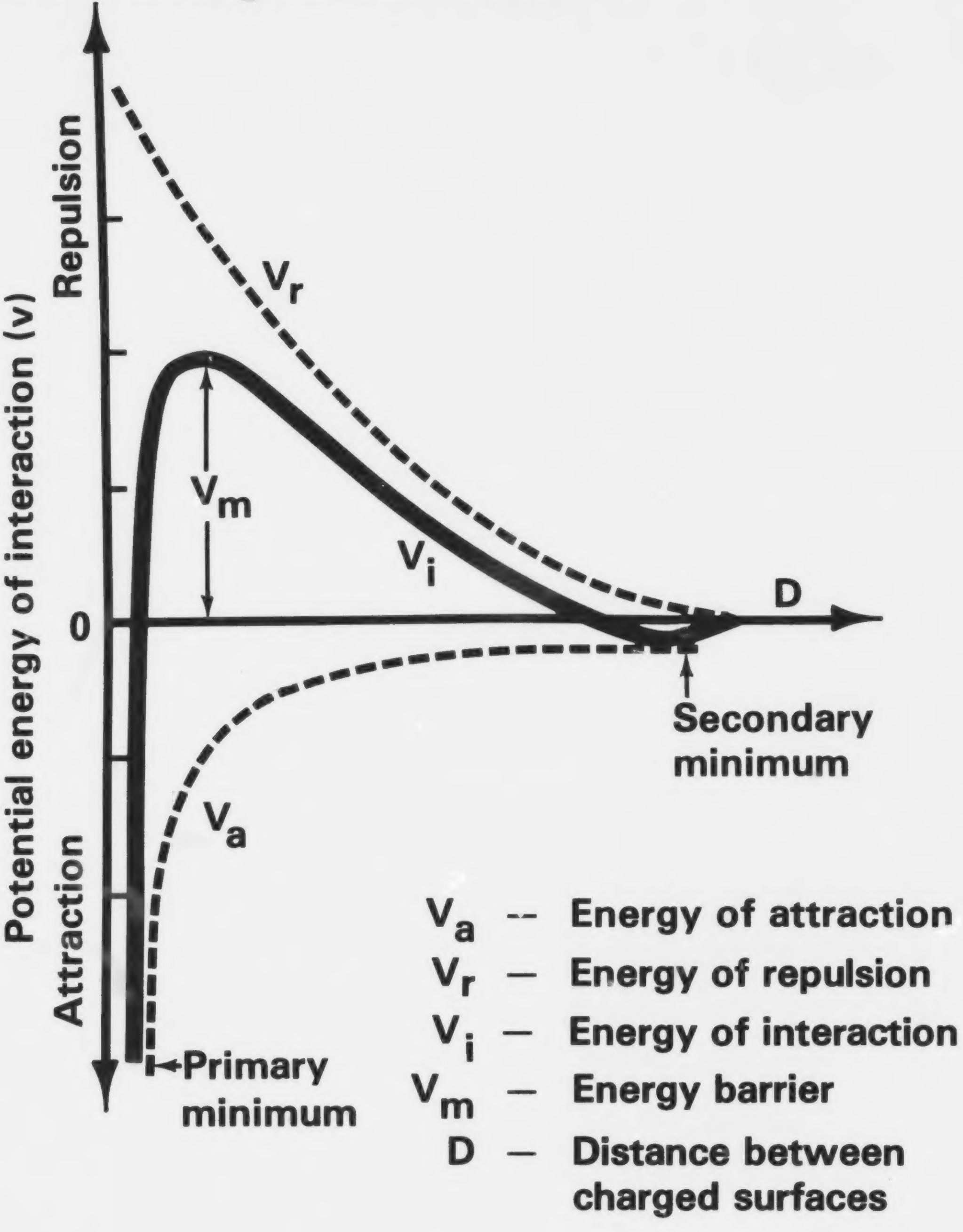

Stern potential
Nernst potential
Zeta potential
Potential
Distance
Bulk of solution
Particle surface
Stern (rigid) layer
Shear plane
Diffuse layer of counter-ions

Figure 31

Potential energy of interaction for two charged surfaces



A graphic illustration of how zeta potential charge neutralization leads to destabilization is illustrated in Figure 32. Letting V_{r1} be the energy of repulsion curve for the particle system, summation of V_{r1} with the energy of attraction (V_a) gives the curve for the energy of interaction (V_{i1}). This curve demonstrates that a repulsion always exists which accounts for the stability of the original colloidal system.

The effect of adding an increment of chemical which reduces the zeta potential by charge neutralization is illustrated by summing the new energy of repulsion curve (V_{r2}) with V_a which yields the energy of interaction curve V_{i2}. This curve has the secondary minimum which provides for loosely flocculated aggregates as previously described for Figure 31. However, an energy barrier still exists which precludes flocculation of particles smaller than 200 A° diameter.

Further addition of chemical which lowers the energy of repulsion curve to that described by V_{r3} yields the interaction curve V_{i3} when summed with V_a. This interaction curve has a large, secondary minimum, no repulsion barrier; thus, all particles are coagulated into aggregates by the attraction energy of the primary minimum.

COLLOID DESTABILIZATION MECHANISMS

Destabilization of the waterborne suspended solids may involve four mechanisms: (1) colloid entrapment or removal via the sweep floc mechanism, (2) reduction in surface charge by double-layer repression, (3) bridging by polymers, and (4) charge neutralization by adsorption.

Colloid Entrapment

Colloid entrapment involves chemical treatment with comparatively massive amounts of primary coagulants; the amount of coagulant used is typically so great in relation to the amount of colloidal matter that the nature of the colloidal material is not relevant. The amount of primary coagulant used may be 5 to 40 times as much as is used for charge neutralization by adsorption. The rate at which the primary coagulants form hydrous metal oxide polymers (Figure 33) is relatively slow and depends chiefly upon water temperature and pH. Coupled with the high concentration used, all negatively charged colloidal material is initially exposed to charge neutralization by the

Figure 32

Influence of electrolytes on interaction energy

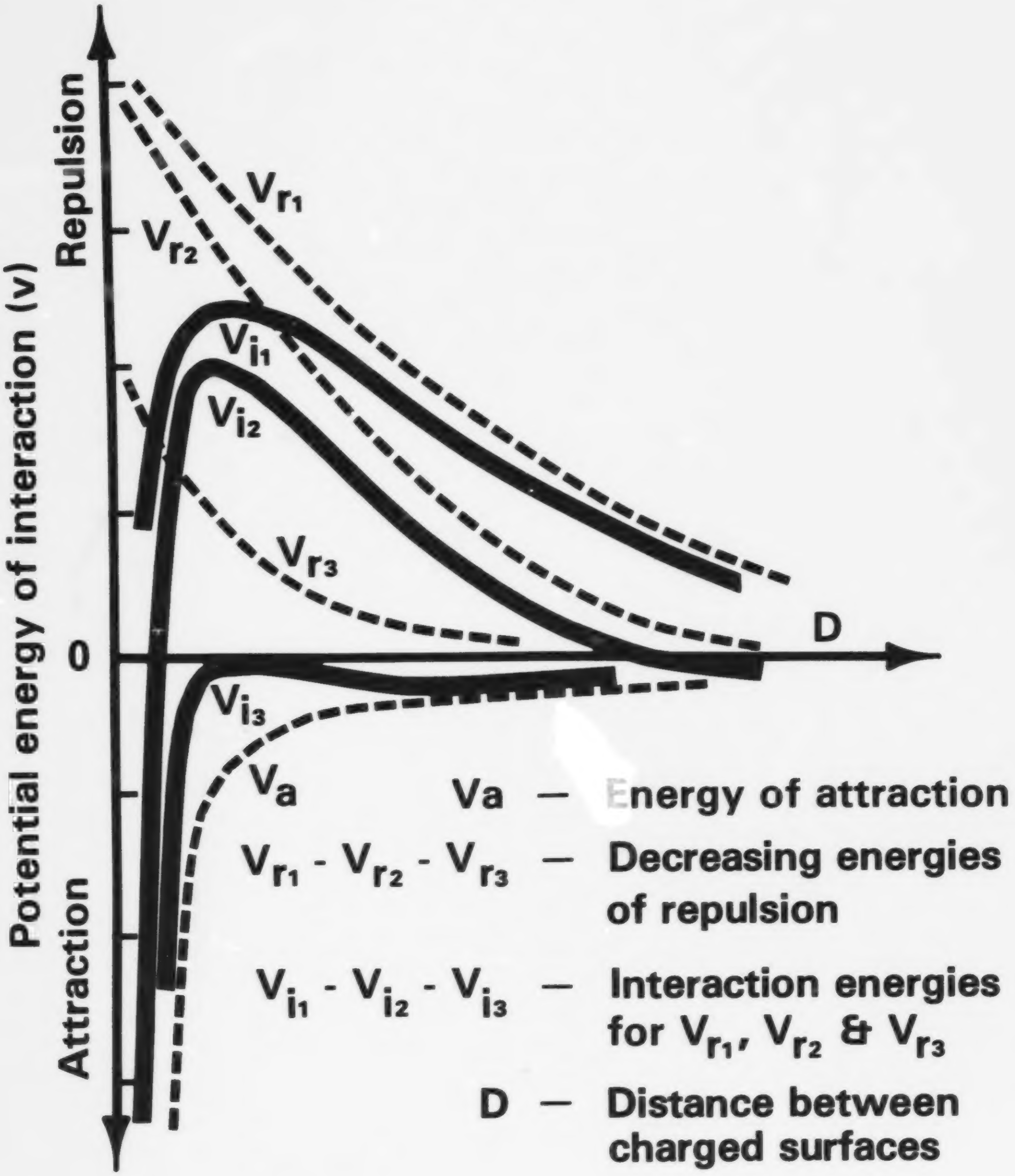
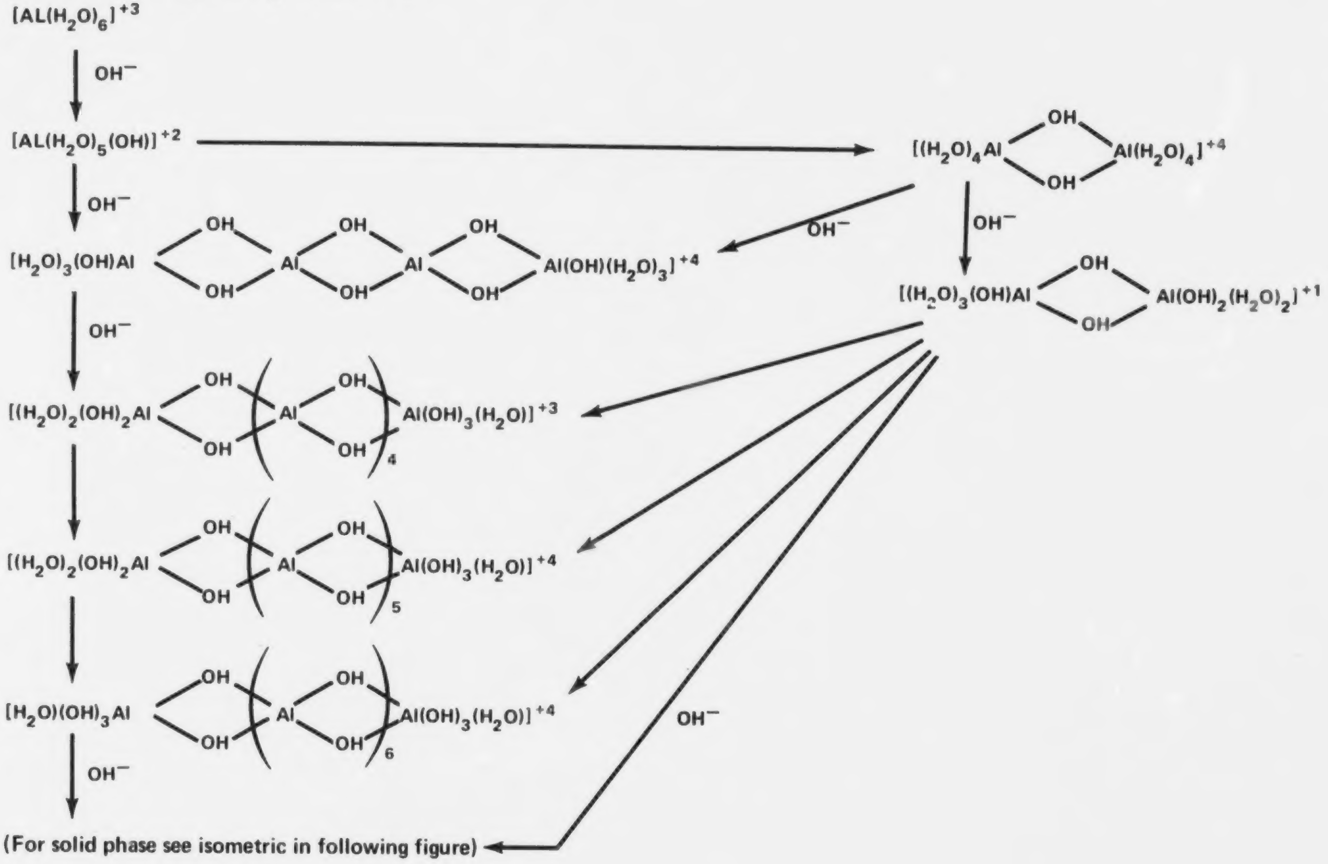


Figure 33

Sequential formation of hydrous aluminum oxide polymers


[AL(H2O)6]+3
OH−
[AL(H2O)5(OH)]+2
[(H2O)4Al(OH)2Al(H2O)4]+4
OH−
[H2O)3(OH)Al
OH
OH
Al
OH
OH
Al
OH
OH
Al(OH)(H2O)3]+4
OH−
[(H2O)3(OH)Al
OH
OH
Al(OH)2(H2O)2]+1
OH−
[(H2O)2(OH)2Al
OH
OH
Al
OH
OH
4
Al(OH)3(H2O)]+3
[(H2O)2(OH)2Al
OH
OH
Al
OH
OH
5
Al(OH)3(H2O)]+4
[H2O)(OH)3Al
OH
OH
Al
OH
OH
6
Al(OH)3(H2O)]+4
OH−
OH−
(For solid phase see isometric in following figure)

transient cationic species. The polymer matrix is 3-dimensional and voluminous, as illustrated by Figure 34, providing for entrapment of solids. As the polymer contracts, freeing solvent water molecules, and settles, the suspended solids remain enmeshed in the settling floc and appear to be swept from the water, hence the description of the process as a "sweep floc" mechanism.

This mechanism is really a "brick forming" mechanism. After all, the electrical surface charge on a brick has no impact on its settling properties. But if the brick is reduced to colloid size, the electric surface charge can have a major impact on the settling properties. The chief objective of colloid entrapment is to form "bricks" so that electrical surface charge effects on settling are minimized.

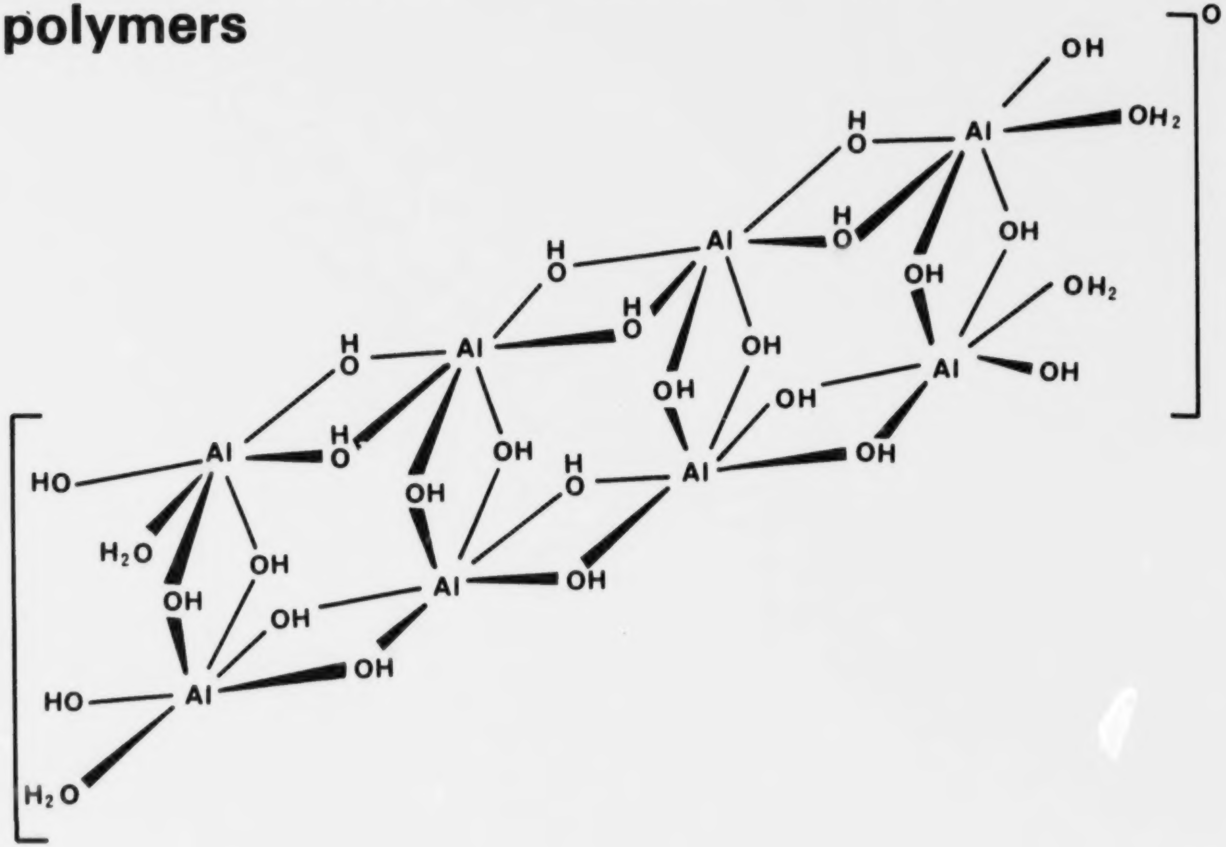
This destabilization mechanism can result in the generation of large amounts of wet alum (or iron) sludges, which are difficult and costly to dewater. Even though it is by far the most widely used mechanism for water clarification, it is not recommended because of the sludge problem and because the use of other mechanisms result in significantly lower operating and capital costs.

Double-Layer Repression

Reduction in surface charge by double-layer repression is caused by the presence of an indifferent electrolyte, which in refineries is chiefly sodium chloride from brackish water usage or salt water ballast, or hardness minerals resulting from evaporative cooling. For water and monovalent electrolytes, the thickness of the double layer is approximately 10 Angstroms (A^o) for 0.1M, 100 A^o for 0.001M, and 1000 A^o for 0.00001M. For double-layer repression of colloid surface charge in brackish waters, the sodium ions of the indifferent electrolyte, which surrounds the colloid particles in order to electrically balance their negatively charged surfaces, have less tendency to diffuse away from the colloid surface as the salinity increases. Some salt concentration may eventually be reached such that the thickness of the double layer may be small enough that two colloids approach each other closely enough that van der Waals forces cause aggregation. An important aspect of double-layer repression is that the quantity of colloidal charge is not significantly reduced, but just the extent to which it extends out from the colloid surface. This relates to the nature of the destabilizing chemical (salt) and its mode of action; i.e., the sodium ions remain free in the solvent and cause rapid dissipation of the charge as the distance from the colloid surface increases.

Figure 34

Example of complex which may exist in precipitated hydrous aluminum oxide polymers


Al
OH
OH_2
H_2O
HO
H O
0

The above-mentioned principles can be visualized by the illustrations of the double layer in demineralized, fresh, and brackish (or salt) waters in Figures 35, 36, and 37, respectively.

For demineralized water, there are not many ions available; therefore, the charge on the particle surface is not reduced much by adsorbed ions in the Stern layer or counterions in the diffuse layer. As a result, the zeta potential is high and extends for a considerable distance into the solvent; i.e., the double layer is thick.

Fresh water, on the other hand, comparatively may contain many salts. As illustrated, the presence of counterions may lead to some adsorption and potential drop across the Stern layer. The concentration of counterions in the diffuse layer is much greater than the demineralized water example and causes the charge to dissipate more rapidly; i.e., the double layer is much thinner than the demineralized water example.

In the example for brackish or salt water, the comparatively high concentrations of sodium ions discourages their diffusion away from the particle surface. The counterions occupying the Stern layer cause an apparent reduction in potential, but are not strongly adsorbed and, therefore, do not permanently alter the surface potential charge to the much lower charge of the Stern potential and the charge actually measured, the zeta potential. The high electrolyte concentration causes any residual charge to dissipate rapidly; i.e., the double layer is very thin.

Double-layer repression, therefore, can flocculate solids for removal by sedimentation, but the colloid fraction is not destabilized and escapes in the effluent. This mechanism does not achieve good results when dissolved air flotation and granular media filtration are used for phase removal. It can conceal definition of optimal chemical pretreatment to achieve best solids' removal results, if the interference of this destabilization mechanism is not recognized. Our refinery experience indicates that the colloidal aggregates destabilized by double-layer repression (loose flocculation by the secondary minimum) are readily redispersed by hydraulic forces as if the net binding forces are very weak. A simple procedure to identify the existence of the double-layer repression mechanism in brackish waters so that it can be avoided and optimized chemical treatment can be achieved has been described.[15]

Figure 35

Representation of electric double layer in demineralized water

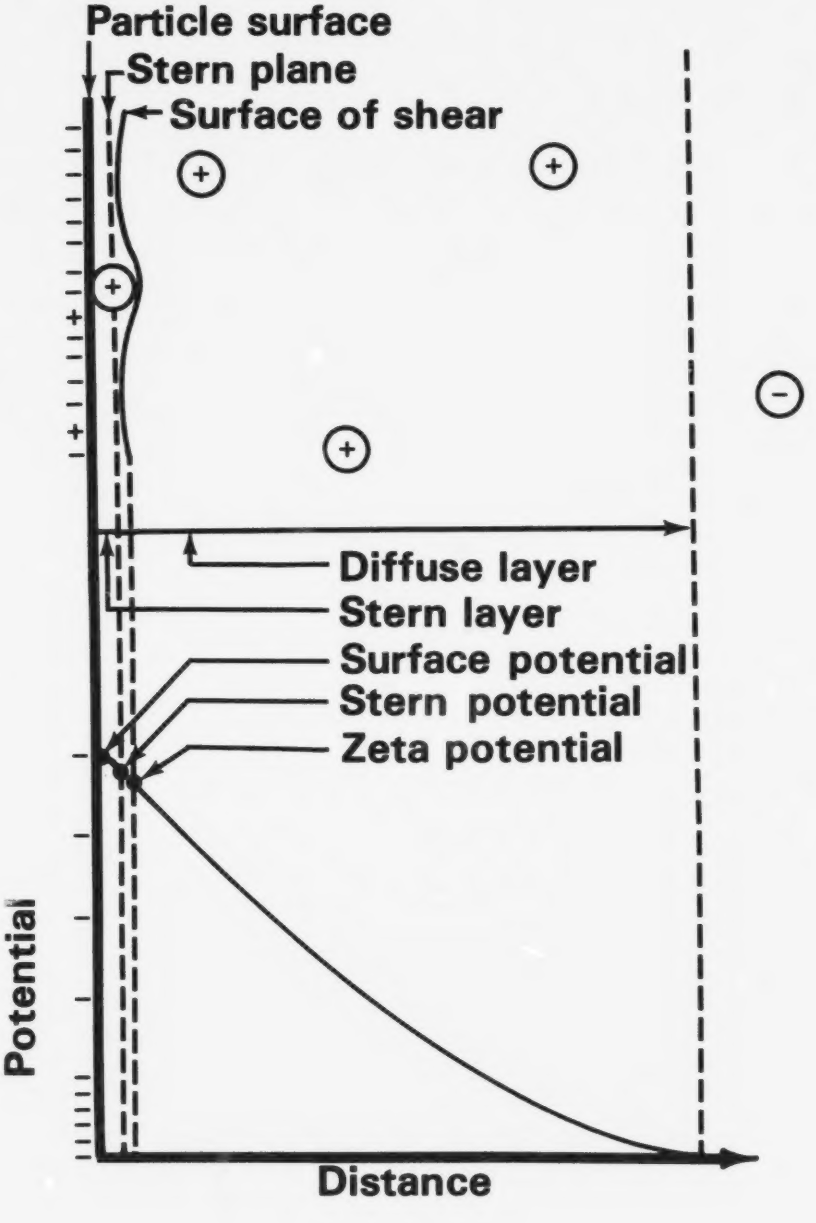

Particle surface
Stern plane
Surface of shear
Diffuse layer
Stern layer
Surface potential
Stern potential
Zeta potential
Potential
Distance

Figure 36

Representation of electric double layer in fresh water

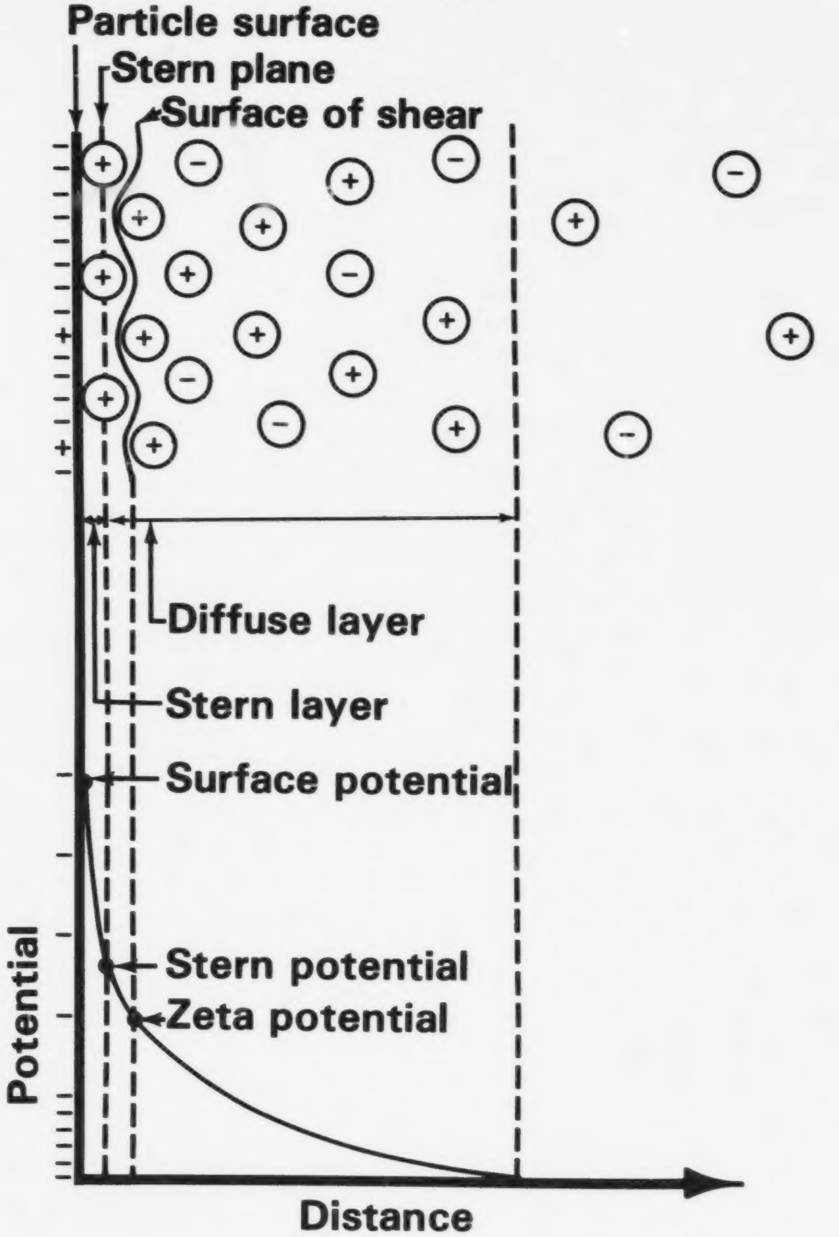
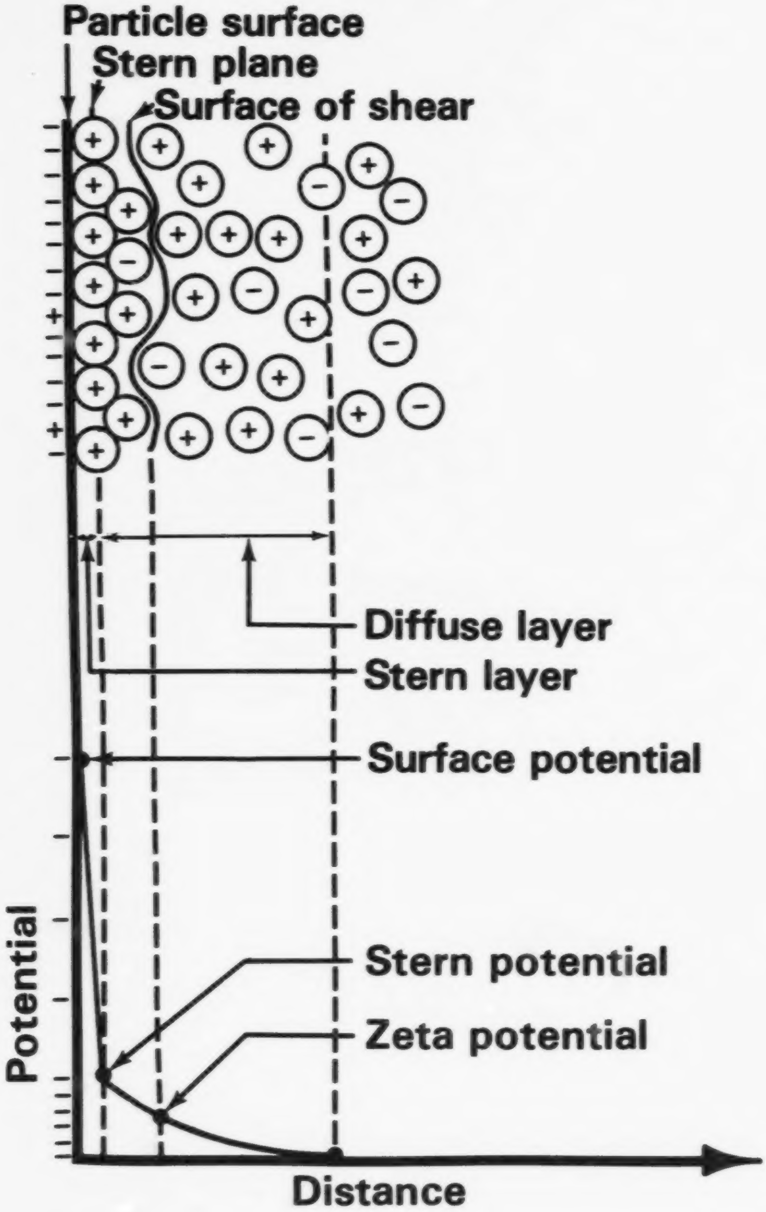

Particle surface
Stern plane
Surface of shear
Diffuse layer
Stern layer
Surface potential
Stern potential
Zeta potential
Potential
Distance

Figure 37

Representation of electric double layer in brackish water


Particle surface
Stern plane
Surface of shear
Diffuse layer
Stern layer
Surface potential
Stern potential
Zeta potential
Potential
Distance

Charge Neutralization

Charge neutralization by adsorption of the destabilizing chemical to the colloid is a key mechanism for optimizing removal of waterborne solids from waters by air flotation, granular media filtration, and sedimentation. The colloidal charge may not only be reduced to zero, but beyond zero; i.e., reversed. Charge neutralization by adsorption infers that the colloid-water interface is changed and thereby its physicochemical properties. It doesn't require much extension of one's imagination to see how this destabilization mechanism can explain those cases where optimal chemical dosages were found and overdosing resulted in a deterioration in, or failure of, air flotation and direct filtration. This phenomenon is more typically experienced using very low-molecular weight polyelectrolytes or surfactant-type molecules with little bridging properties. A graphic illustration of how zeta potential charge neutralization leads to destabilization has been described in relation to Figures 29 and 30.

Bridging

Bridging by organic and inorganic polymers describes the destabilization mechanism where the molecules of the added chemical attach onto two or more particles causing aggregation. There are two kinds of bridging; polyelectrolyte bridging between dissimilarly and similarly charged materials.

An example of the first kind is the bridging of negatively charged colloids by cationic polyelectrolyte. Thus, this kind of bridging also involves the mechanism of charge neutralization. Because of the coulombic attraction involved, this destabilization is not difficult to perceive.

Examples of the second kind illustrate their importance. Although negatively charged, weakly anionic organic polymers are especially useful for aggregating and binding together negatively charged particles into large agglomerates. When the zeta potential of the particles is initially adjusted to about 0 to -5mV before treating with the anionic polymer, the resulting agglomerate will be tough and resist redispersion by hydraulic forces in an air flotation unit. If the zeta potential of the particles is initially much more negative, weakly anionic polymers still will effectively bind the particles into large agglomerates. In this latter example, the net binding forces are weak and the agglomerates are easily redispersed. Thus, this application is suitable for sedimentation processes but not air flotation.

The importance of this second kind of bridging mechanism is emphasized when it is recognized that this is the mechanism of the activated sludge process; i.e., a negatively charged biopolymer destabilizes and flocculates the negatively charged particles in sewage and industrial wastes!

This important property of biopolymers and organic polymers relates to their molecular weight, polarizability, unique electrical properties, and the size of the particles to be flocculated. An electrical model proposing a mechanism for this seeming anomaly is described in a later section.

DESTABILIZING CHEMICALS

Primary Coagulants

Efficient destabilization of colloidal suspensions using salts of iron and aluminum as primary coagulants must recognize the properties of these primary coagulants. The chief properties of concern are the ZP-pH relationships and hydrolytic reactions.

Stumm and O'Melia[16] describe the equilibrium composition of solutions in contact with precipitated primary coagulants in the interesting manner shown in Figures 38 and 39. These diagrams are calculated using constants for solubility and hydrolysis equilibria. The shaded areas A and B we have added in each figure are approximate operating regions for air flotation and clarifiers by colloid entrapment (region A) and direct filtration by charge neutralization (region B). Both regions are assumed to cover a pH range of 6.0 to 8.5. The coagulant dosage ranges from 33 to 200 mg/l in region A and 3.3 to 20 mg/l in region B. Operation in region B typically requires supplementation with cationic polyelectrolytes. These figures are useful in the interpretation of some of our air flotation unit results.

With reference to Figure 40, the isoelectric point for ferric hydroxide coincides with the region of minimum solubility, and the operating regions for water treatment (destabilization) yield a hydrolyzed primary coagulant with a desirable positive zeta potential.

In many refinery situations, however, it is difficult to use this attractive condition because the presence of sulfides and strongly

Figure 38

Equilibrium compositions of solutions in contact with $Al(OH)_3$

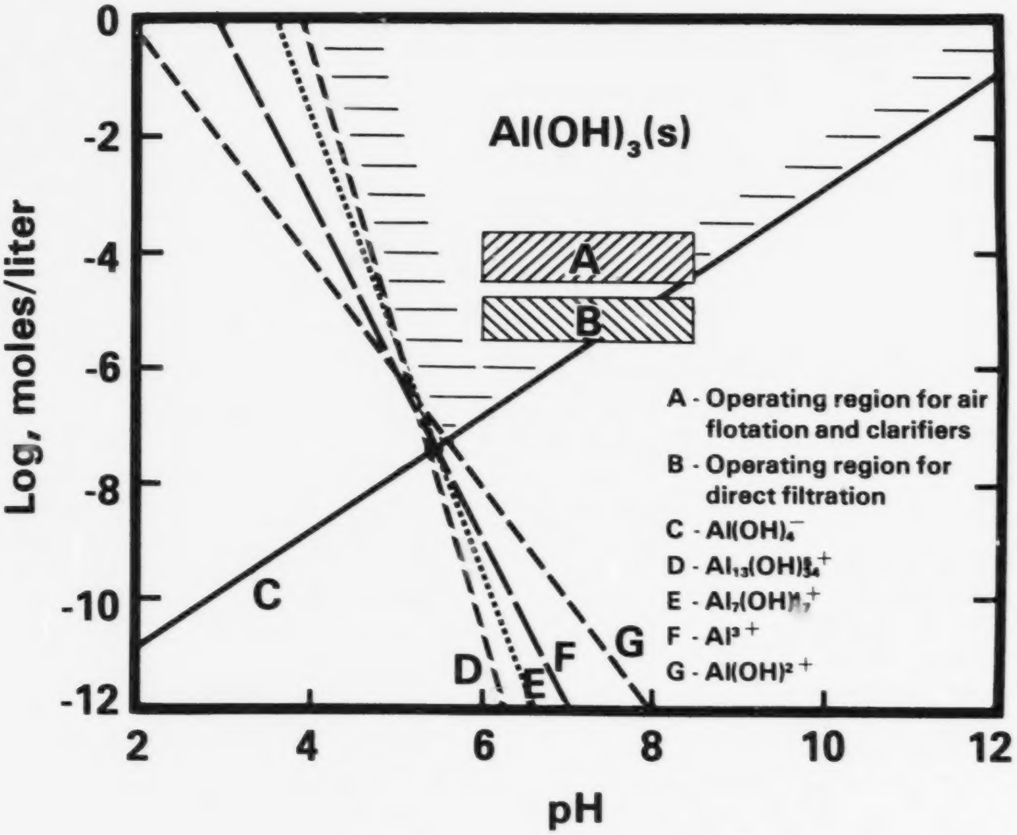


Figure 39

Equilibrium compositions of solutions in contact with $Fe(OH)_3$

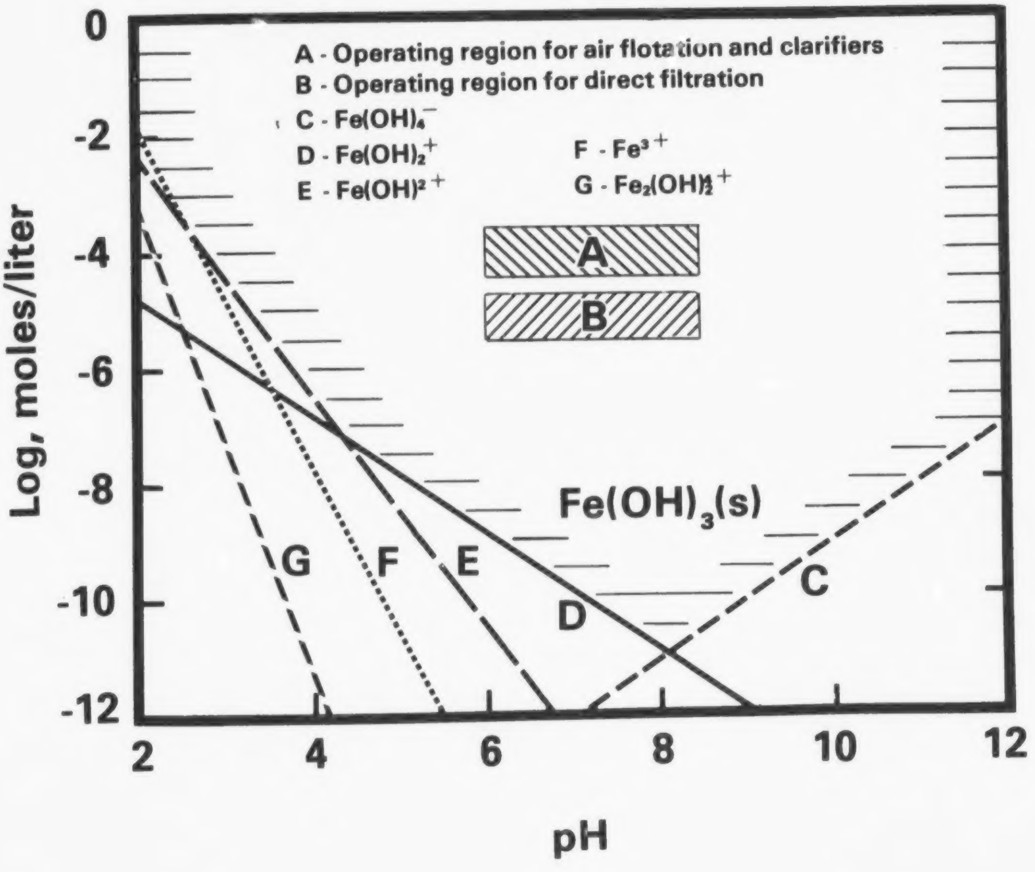
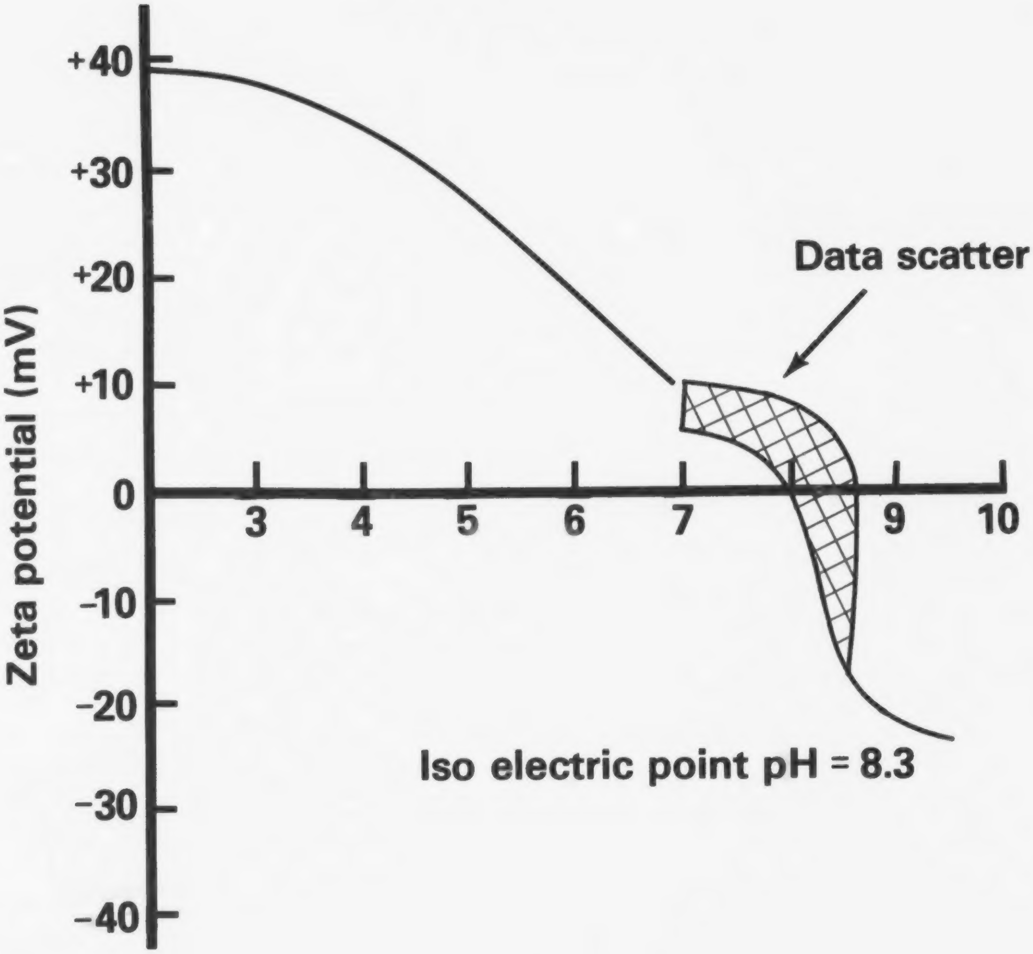


Figure 40

Zeta potential of colloidal Iron Hydroxide solutions plotted as a function of pH



reducing conditions cause the reduction of ferric to ferrous iron (soluble) and the formation of mixed iron sulfides with no coagulation powers. In fact, in some refinery waters, the use of iron coagulants at modest dosages may contribute to stabilizing solids rather than destabilizing them.

While alum has no redox or sulfide chemistry comparable to iron, its amphoterism and solubility pose definite limitations on alum usage. With reference to Figure 36, a substantial portion of operating region B lies in the area where alum is soluble and the predominant equilibrium species is negative, $Al(OH)_4^-$. In the more acidic part of region B, however, the concentration of equilibrium ionic species is very much lower, and much less negative. Considering these data, it is not unexpected that investigators consistently report optimal coagulation/flocculation results with alum at a pH of 5-6.

With inspection of Figure 38, one may question why alum is effective at all for neutralizing negatively charged colloids in the indicated operating regions. One approach to explaining observed performance requires understanding that the data are equilibrium data; but before equilibrium is reached, substantially different conditions exist.

Alum very readily hydrolyzes to form polymers in a complex manner not well defined. The hydrolytic pathway and reaction rates are affected by pH, temperature, other ions, etc. One hypothesized route which includes different aluminum hydrolysis products which are known to exist is outlined in Figure 33. When alum is added to water in amounts which exceed the solubility limits, sequential reactions occur until the ultimate precipitate is formed and the ionic species appropriate to the pH equilibrate with the precipitate. The hydrolytic reactions are not instantaneous, and as they proceed, positively charged hydroxo polymers are formed which are available for colloid adsorption. The hydrolyzed species have enhanced adsorption capabilities, possibly due to larger size and less hydration and the presence of coordinated hydroxide groups.[16] In solutions more alkaline than the isoelectric point, the positively charged polymers are transient and, at equilibrium, anionic polymers prevail.

In modestly alkaline solutions, the transient positively charged polymers appear to contribute to destabilization of colloids. On the other hand, in solutions more acidic than the isoelectric point, the positively charged polymers prevail at equilibrium and destabilization of colloids may be achieved at significantly lower coagulant treatment levels.

In Figure 40, the zeta potential of colloidal iron hydroxide solutions is plotted as a function of pH. The zeta potential decreases in positive charge as the pH increases until the isoelectric point is reached at a pH of 8.3 at which the charge reverses. In the vicinity of the isoelectric point, the charge may vary as indicated. Alum has a similar zeta potential -pH relationship as shown in Figure 41. The zeta potential may be negative or positive over the pH range of 7.0 to 7.8.

Salts appear to interfere with the coagulative powers of alum by anion penetration of the alum polymer by chloride ion. Anion penetration, the replacement of a coordinated group such as aquo hydroxo, or another anion, can be visualized with reference to Figure 33. Chloride ion is a highly mobile, nonhydrated, electronegative ion that at high concentrations penetrates the hydrous aluminum oxide polymer, impairs the olation of alum to polymers, and reduces the formation, or charge, of the transient cationic alum polymers which are very important to colloid charge reduction.

Polyelectrolytes

Polyelectrolytes used as water-treating chemicals are macromolecules having many charged groups and may be classified as nonionic, anionic, and cationic depending upon the residual charge on the polymer in solution.

Nonionic Polyelectrolytes--

Commercially available nonionic polyelectrolytes seem to be of only one type, polyacrylamide (PAM), as shown in Figure 42. Presumably, this is because of availability, low cost, well-understood polymerization chemistry, and lack of demand. We have not found nonionic polyelectrolytes to be the polyelectrolyte of choice in any of our work thus far.

Anionic Polyelectrolytes--

Commercially available anionic polyelectrolytes also seem to be of only one type; i.e., partially hydrolyzed PAM as shown in Figure 43. Anionics can be made by hydrolyzing polyacrylamide, or copolymerizing acrylamide and acrylic acid. Methacrylic acid, etc., is another example of a charged monomer that could be used.

Figure 41

Zeta potential — pH plot for Aluminum Hydroxide

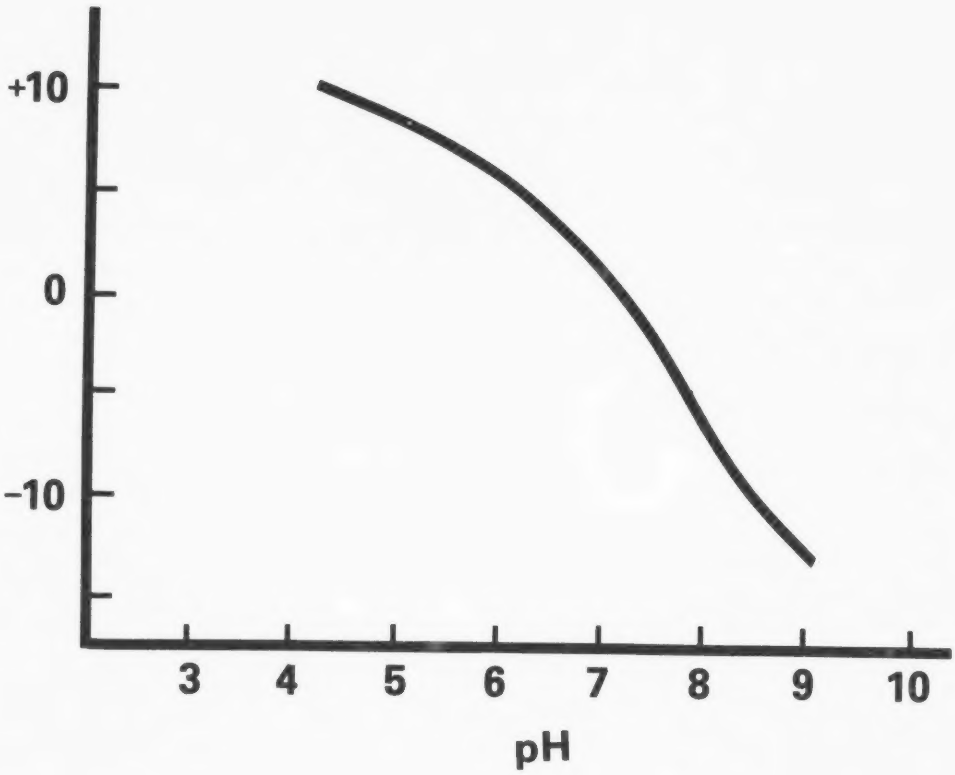
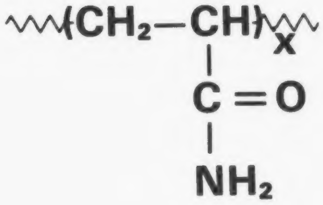


Figure 42

Nonionic polyelectrolyte

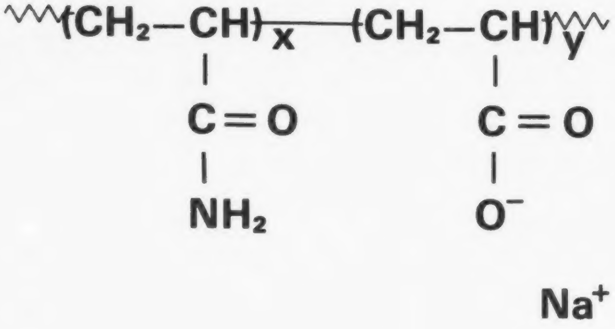


$$\sim\!\!\sim\!\!\left(CH_2-\underset{\substack{|\\ C=O\\ |\\ NH_2}}{CH}\right)_x\!\!\sim\!\!\sim$$

Polyacrylamide

Figure 43

Anionic polyelectrolytes (from hydrolyzed polyacrylamide)



$$\sim\!\left(CH_2-\underset{\underset{\underset{\underset{NH_2}{|}}{C=O}}{|}}{CH}\right)_x\!\!-\!\!\left(CH_2-\underset{\underset{\underset{\underset{O^-}{|}}{C=O}}{|}}{CH}\right)_y\!\sim \qquad Na^+$$

The ratio of the carboxylic acid group to the amide group determines the anionic strength of the polymer:

% Amide	% Acid	Character
100	0	Nonionic
95	5	Very weakly anionic
90	10	Weakly anionic
80	20	Anionic
70	30	Strongly anionic
55	45	Very strongly anionic

There are polyelectrolytes available much higher in acidic group content, the maximum case of course being polyacrylic acid. Our experience indicates these to be useful chiefly in industrial processes. We find the most consistently useful anionics in waste water treating to be those having 5% to 20% acid groups.

The chief use of anionics is to perform a bridging function. The superb properties of the acrylamide based anionics that make them particularly effective in this service is their molecular weight and polarizability. Anionic polyelectrolytes of about 15,000,000 molecular weight are commercially available as powders and in liquid form.

Cationic Polyelectrolytes--

The charge on cationic polyelectrolytes is typically derived from the nitrogen atom in the form of secondary and tertiary amines and quaternized ammonium compounds. One disadvantage of secondary and tertiary amines on the industrial waste water scene is that their isoelectric points are probably typically about 8.3-8.8. When used on the alkaline side of their isoelectric point, their effectiveness diminishes rapidly.

In the treatment of waste waters, it must be recognized that cationics react chemically with some anions, forming chemical bonds which then impair the performance of the cationic for charge neutralization and bridging. Impairment of performance is typically by requiring greater amounts of the cationic to destabilize a system in the presence of interfering anions.

The presence of sulfides, or hydrosulfides, can be particularly destructive to the use of cationics. Apparently, sulfides form strong covalent bonds with the cationic functional group and almost completely eliminate its charge effects. Phenolics and chloride (salinity) are examples of other anions we have encountered which impair the functioning of cationics.

Molecular weight of the cationics can relate to their use. For example, if the unit operation is granular media filtration, performance is optimized using the charge neutralization mechanism and building a microfloc which penetrates the granular media bed and maximizes filter run length. Cationics lower on the molecular weight spectrum are used in this instance.

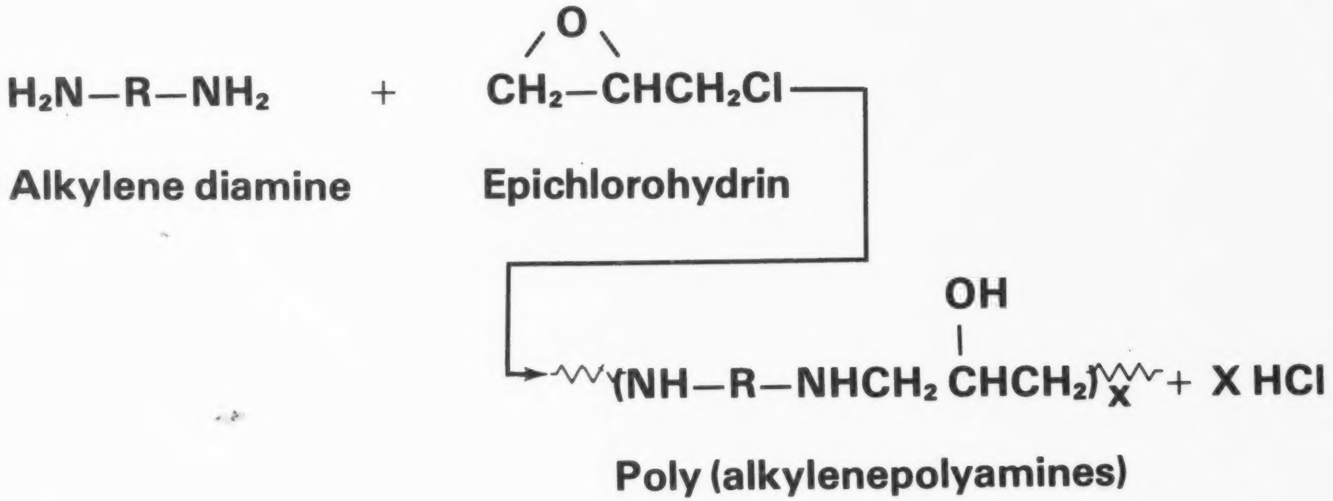
Cationic Polyelectrolyte Types--

In contrast to the anionic and nonionic polyelectrolytes available, cationic polyelectrolytes commercially available provide to the user a wide range of molecular types and weights. The various major manufacturers seem to have carved out a special area of manufacturing expertise, but the comparative performance of the various cationics have not been quantified in specific applications such that it can be said a specific chemical type, or molecular weight range, is the cost-effective choice. The effect of anionic antagonists also have not been determined. Historically, chemical usage is determined by beaker tests, a primitive means at best.

Amine type--A popular and very effective cationic polyamine made from alkylenediamines (for example, dimethylamine) and epichlorohydrin (EPI) is illustrated in Figure 44. Proprietary manufacturing expertise is involved in selecting the alkylenediamine, mole ratio of reactants, and reaction conditions to promote branching and cross-linking of the intermediate reaction product to form the final product. These DMA/EPI cationics are available in the molecular weight range from about 2,000 to 250,000.

Figure 44

Cationic polyelectrolyte (Polyaddition - condensation type)


Alkylene diamine
Epichlorohydrin
Poly (alkylenepolyamines)

$$H_2N{-}R{-}NH_2 + CH_2{-}\overset{O}{CH}CH_2Cl \longrightarrow \sim\!(NH{-}R{-}NHCH_2\overset{OH}{\overset{|}{C}}HCH_2)_x\!\sim + X\,HCl$$

A historically popular cationic substitutes ethylenedichloride for EPI as shown in Figure 45. These products can also be thermoset to the effective cationic shown in Figure 46.

Other poly (alkylenepolyamines) are available manufactured from ammonia and either EPI or DMA.

Because simple, low molecular weight polyamines are used as starting materials, the product is not necessarily a polyamine. This is because polyamines are still functional and can be alkylated and converted to quaternary compounds:

$$R\text{-}NH_2 \;+\; 2R'X \longrightarrow R\text{-}N\text{-}R'_2 \;+\; (2HX) \qquad \text{equa.1}$$

$$R\text{-}N\text{-}R'_2 \;+\; R'X \longrightarrow R\text{-}\overset{\oplus}{N}\text{-}R'_3\overset{\ominus}{X} \qquad \text{equa.2}$$

Dimethyl sulfate is also a popular alkylating agent.

A popular, effective, widely available cationic polyelectrolyte is prepared from diallyldimethylammonium chloride (DADMAC). This quaternized cationic is shown in Figure 47. DADMAC's are available over the molecular weight range of about 40,000 to several million.

Acrylamide is a key component in some excellent cationic polyelectrolytes in addition to being the basis of nonionics and anionics. For example, Figures 48 and 49 show PAM/DMAM and PAM/DMAEM. Quaternizing these cationics make especially effective quaternary compounds of high molecular weights; i.e., up to about 5,000,000. They are excellent for charge neutralization and bridging, therefore, air flotation applications.

Acrylamide provides a means to achieve high molecular weights in cationics, as in the previous figures, and by copolymerization with, for example, DADMAC as shown in Figure 50. Cationic copolymers of PAM/DADMAC are available containing from .05 to .7 mole fraction of PAM. The molecular weights vary from about 500,000 to 3,000,000; the greater the molecular weight, the greater the mole fraction of PAM.

Figure 45

Cationic polyelectrolytes (polyamines)

$$H_2N{-}R{-}NH_2 \quad + \quad Cl{-}R^1{-}Cl \longrightarrow \sim\!\sim\!\left(HN{-}R{-}NH{-}R^1\right)_x\!\sim\!\sim$$

Figure 46

Cationic polyelectrolytes (Polyamines)

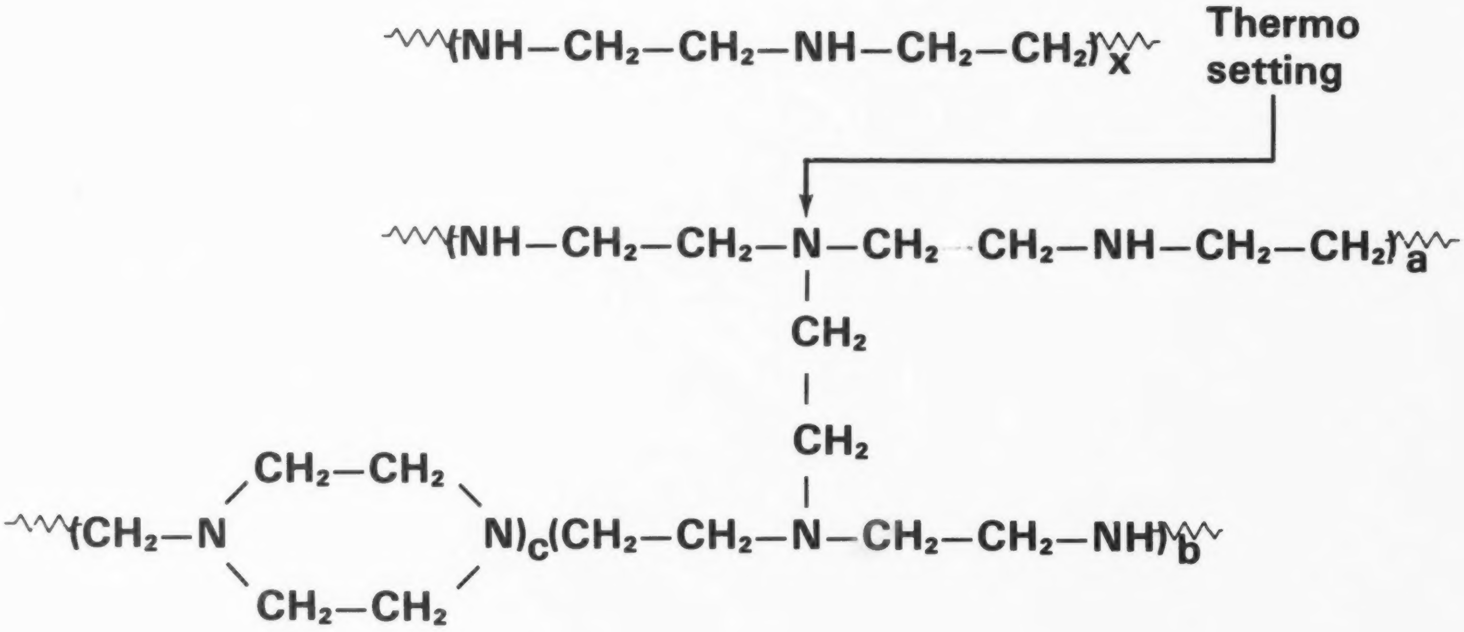
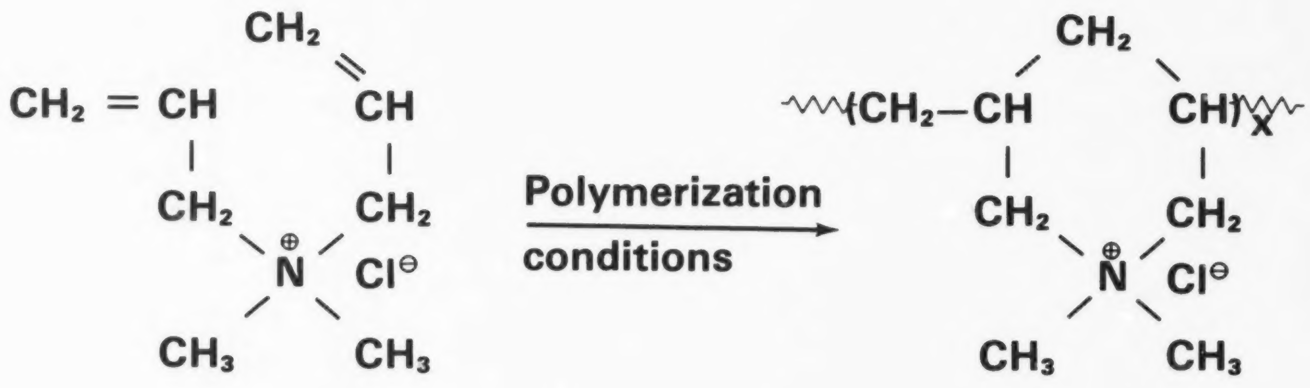

Thermo
setting

Figure 47

Cationic polyelectrolyte

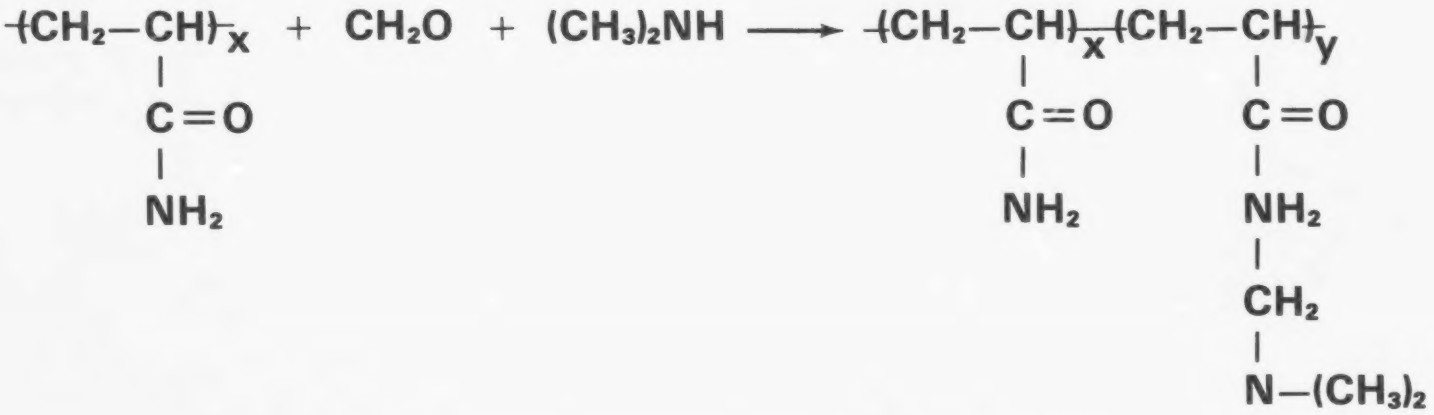

Polymerization
conditions

Diallyldimethylammonium chloride (DADMAC)

Poly (DADMAC)

Figure 48

Cationic polyelectrolyte (Mannich type)

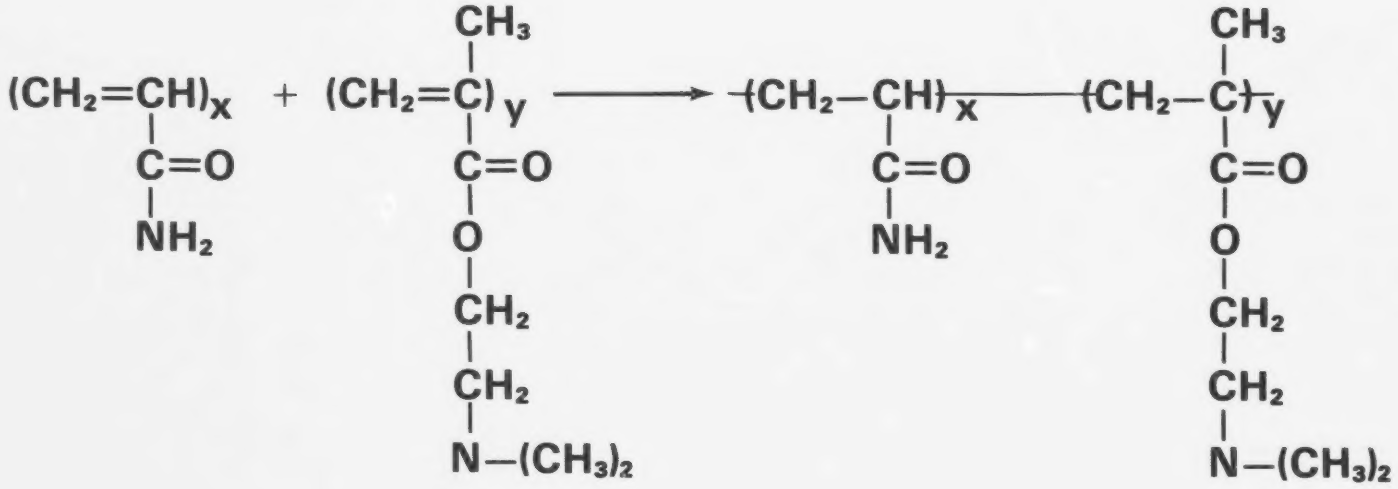


$$\left(CH_2-\underset{\underset{NH_2}{|}}{\underset{C=O}{\overset{}{CH}}}\right)_x + CH_2O + (CH_3)_2NH \longrightarrow \left(CH_2-\underset{\underset{NH_2}{|}}{\underset{C=O}{CH}}\right)_x\left(CH_2-\underset{\underset{\underset{\underset{N-(CH_3)_2}{|}}{\underset{CH_2}{|}}}{\underset{NH_2}{|}}}{\underset{C=O}{CH}}\right)_y$$

Polyacrylamide Formaldehyde Dimethylamine PAM/DMAM

Figure 49

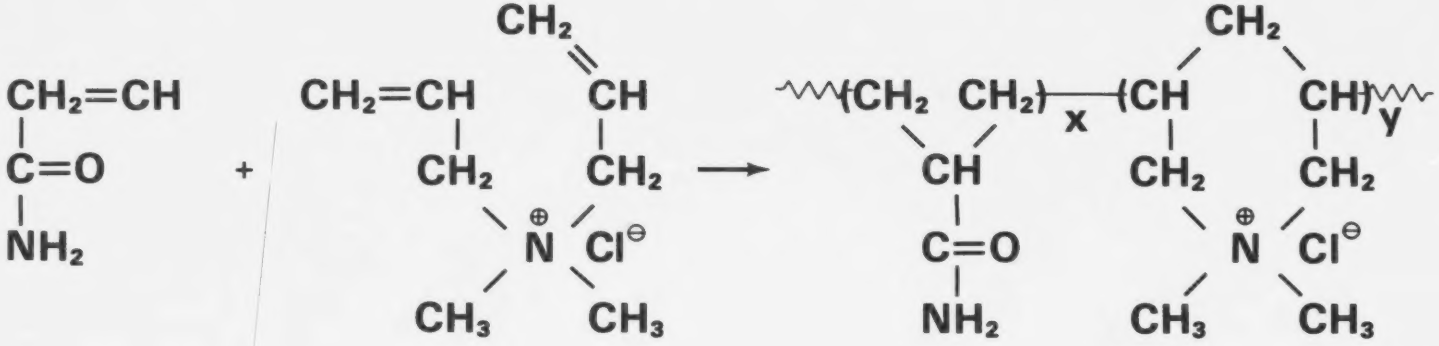
Cationic polyelectrolyte (PAM—DMAEM copolymer)



Acrylamide **Dimethylaminoethylmethacrylate** **PAM/DMAEM**

Figure 50

Cationic polyelectrolyte Acrylalmide/DADMAC copolymer)



Acrylamide DADMAC DADMAC is .1 to 40 mole %

Polyelectrolyte Charge--

In solution, the cationic and anionic polyelectrolytes are dissociated into polyvalent macroions and a large number of small ions of opposite charge (counterions). The macroion is highly charged, which is the cause for the characteristic properties of the polyelectrolytes. Most of the macroions are long, flexible chains, their size and shape depending on the macroion charge and interaction with counterions. With increasing charge, the macroion extends; with decreasing charge, the macroion assumes a contracted random coil.

The source of the charge is illustrated by the polyacrylates, a widely used polymer. In distilled water, polyacrylic acid's carboxylic functional group is only slightly dissociated. The addition of NaOH reacts with the carboxylic groups causing them to dissociate leaving a charge on the macroion and producing sodium counterions (as illustrated in Figure 41).

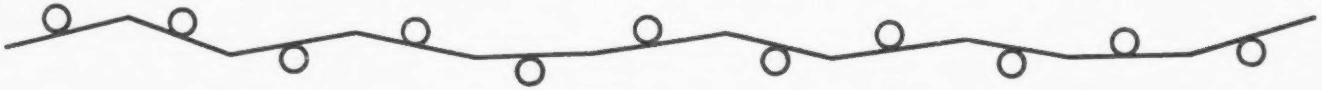
The number of monomers in a polyelectrolyte may range from about 10^2 to 10^5. Molecular weights cited for synthetic polyelectrolytes are somewhat meaningless, since they may be estimated by osmotic pressure, light scattering, ultracentrifugation, viscosity, etc., techniques which do not generate the same value; and, of course, a commercial polyelectrolyte consists of many polymers of varying molecular weight.

In the case of polyacrylic acid, the length of each monomer along the chain is $2.5A^o$ (Angstroms). Since the radius of each atom is about $1A^o$, a polymer macroion is envisioned as a flexible cylinder like a garden hose. When the side chain of ionizable groups is short, the macroion looks like a cylinder with charges on its surface (Figure 51A). When, the side chain of ionizable group is long, the macroion looks like a cylinder with radiating short branches charged at the ends (Figure 51B).

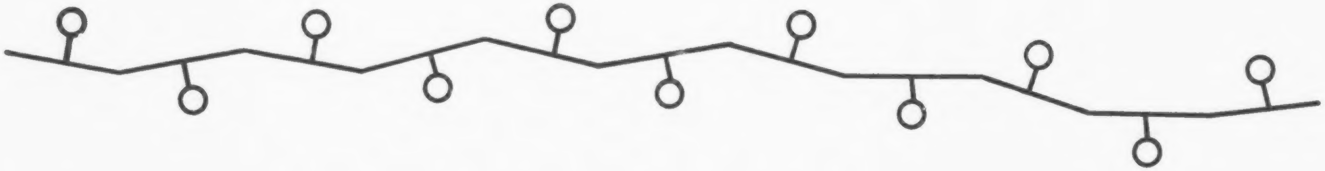
The flexibility of the macroion exists because bonds in the main chain can rotate around the neighboring bond keeping the bond angle constant. The macroion has, therefore, a very large number of conformations classified as either random coil or helix (extended). In the random coil, there is no long-range regularity in the bond angles. In the helix, the chain bond angles have a long-range regularity.

Figure 51

Examples of extended macroions with short and long side chains



A. Extended macroion with charged groups on short side chains



B. Extended macroion with charged groups on longer side chains

The two kinds of conformations are illustrated in Figure 52. Extended and contracted states fit the random coil category if there is no repeated angle regularity, and the random coil, therefore, does not necessarily refer to a spherically contracted state of the chain, but may take a cylindrical form.[17]

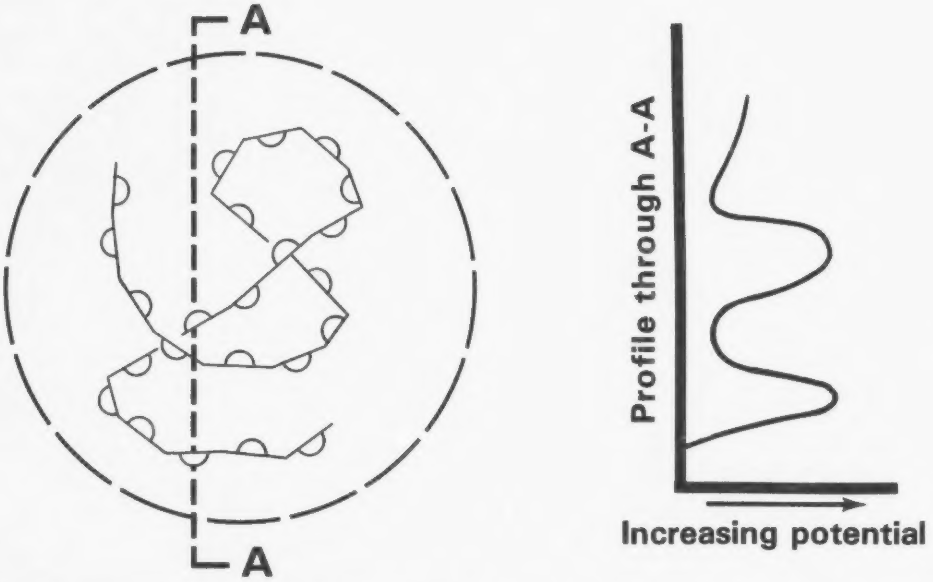
The ionizable groups on the macroion are the source of an electric field. Neglecting the effect of counterions, the field about a random coil macroion is shown qualitatively in Figure 52 and an extended macroion in Figure 53. In these examples, there are potential maxima in the region of the charged functional groups. Outside the region of potential maxima, there is a lesser potential field that might be described as a potential tunnel. This is illustrated isometrically in Figure 54. When the macroion is in the random coil conformation as shown in Figure 55, there is an additional weak potential region (B) in the macroion's sphere of influence. A fourth potential region is the solution where there is no potential effect due to the macroion.

These four potential regions each have a different effect on the counterions. In the three potential regions within the macroion's sphere of influence, counterions can be considered as being bound to the macroion. In the region of potential maxima, the bound counterion may be localized at charged functional groups forming ion pairs. In a mixture of counterions with different valences, increasing the concentration of di- and trivalent ions causes the bound multivalent ions to increase and only monovalent ions remain in solution as shown in Figure 56. In the potential tunnel region, the bound counterions are mobile, as they are in the weak potential region.

The mobile counterions establish an equilibria, therefore, between the potential tunnel, weak potential field in the sphere of influence, and the solution. At high values of functional group charge density along the macroion chain, most of the counterions are retained in the potential tunnel, and the concentration of counterions in the spherical region of influence is not much different from the concentration in the solution as illustrated in Figure 55. The "screening" effect of counterions might be a barrier that hinders the approach to colloidal particles so that strong chemical binding forces can't come into play, or the osmotic forces caused by the bound counterions cause water molecules to accumulate in the potential tunnel region. This latter case would have the effect of increasing substantially the size of the potential tunnel, which would require more energy for colloidal particles to penetrate and permit van der Waals attractive forces to function.

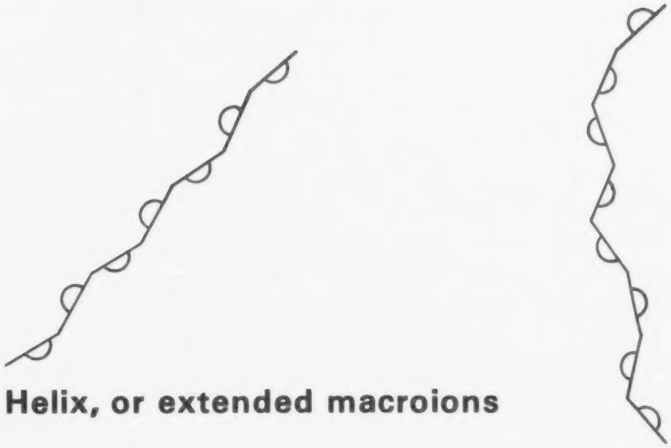
Figure 52

Macroion conformations and a potential profile


A
A
Profile through A-A
Increasing potential

A. Random coil conformation showing sphere of influence

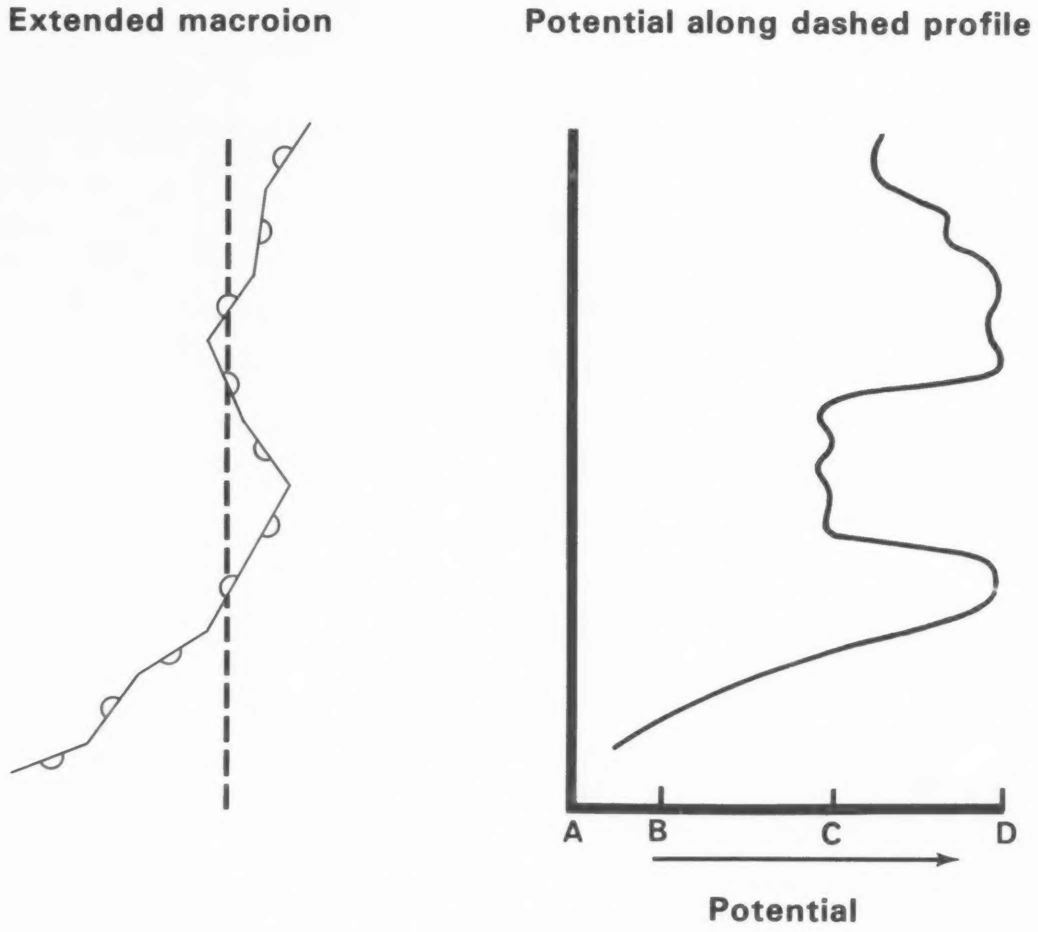
B. Potential profile through random coil macroion



C. Helix, or extended macroions

Figure 53

An extended macroion and its associated potential field


Extended macroion
Potential along dashed profile
A
B
C
D
Potential

A Solution potential

B Weak potential field

C Potential tunnel

D Potential maxima

Figure 54

Isometric showing potential maxima and potential tunnel fields

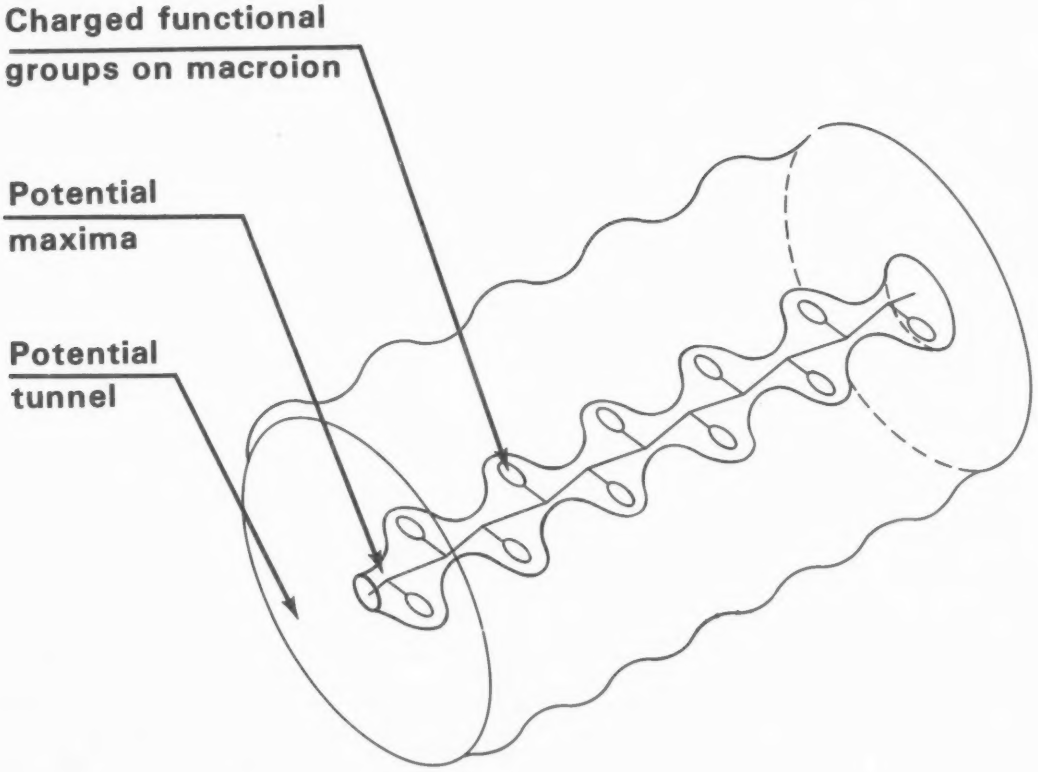
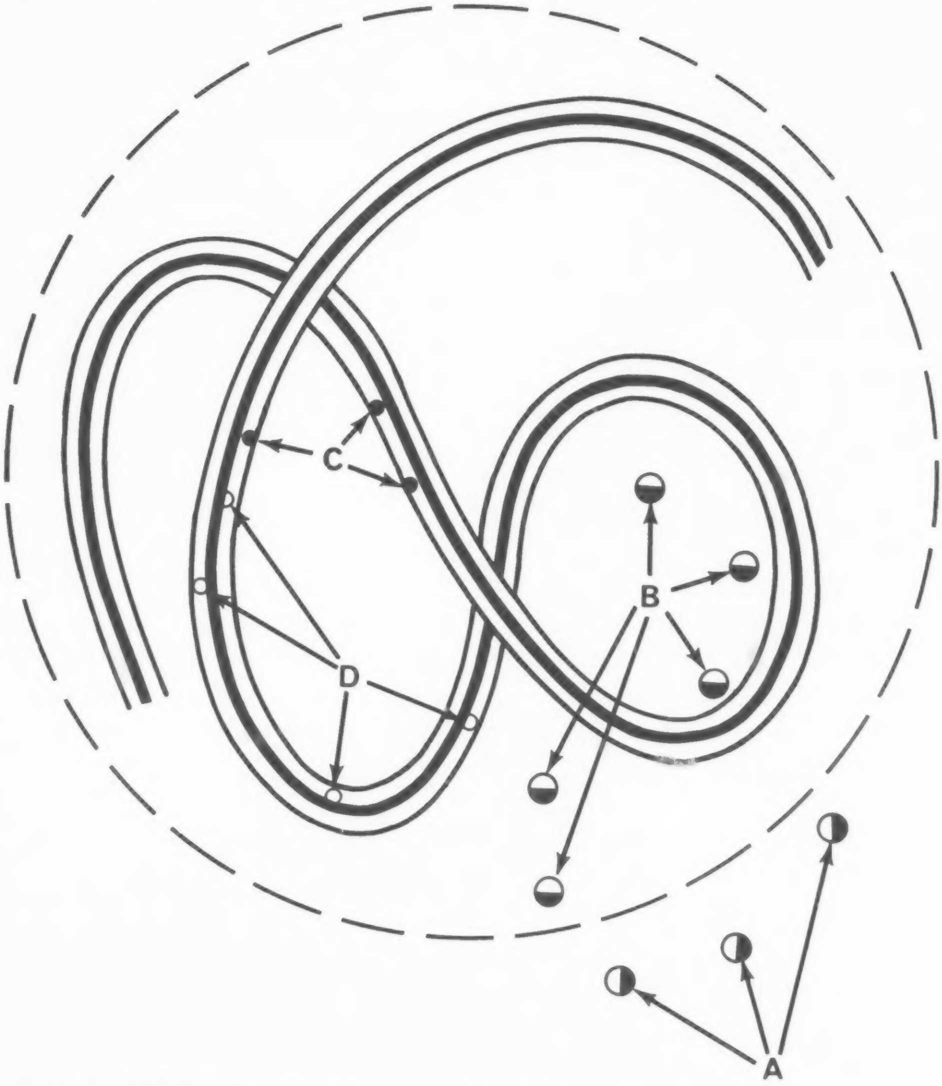

Charged functional groups on macroion
Potential maxima
Potential tunnel

Figure 55

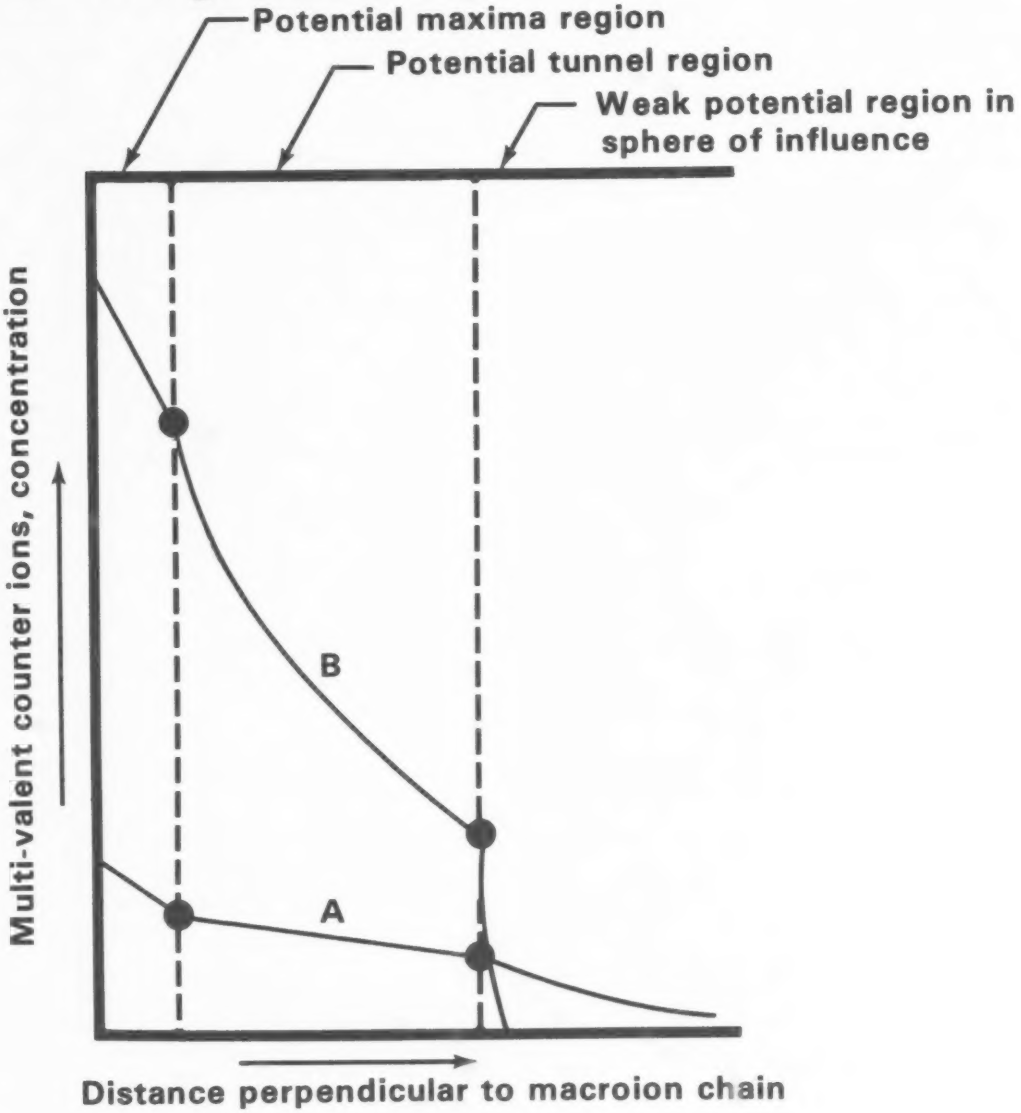
Macroion in random coil conformation showing four potential regions



A – No potential effect; i.e. the solution
B – Weak potential in the macroion's sphere of influence
C – Potential tunnel
D – Potential maxima near charged functional groups

Figure 56

Attraction of multivalent counter ions to charged macroion



A - Distribution of multivalent counter ions in a mixture of counter ions with different valences

B - Distribution of multivalent counter ions when the ratio of di- and trivalent ions are increased

THE DIMENSIONS OF THE PROBLEM

Having discussed the electrical properties of solids that stabilize dispersions, destabilization mechanisms, the properties of destabilization chemicals, the DLVO Theory, attention can now focus on the "dimensions" of the problem before describing some proposed reaction mechanisms to explain the behavior of systems. The behavior of the systems will ultimately be related to the performance of the dissolved air flotation process.

The dimensions of the various components involved in colloid destabilization vary a million-fold, from a few A^o to more than 10^6 A^o as shown in Table 32.

Where color is not a significant factor, the problem is usually one of causing colloidal particles down to about 1000 A^o in diameter to aggregate. When a clarifier or dissolved air flotation unit is used for phase separation, it is desirable to build aggregates to fairly large size, say greater than 10^6 A^o. On the other hand, when filters are used, simply destabilizing the colloidal particles is sufficient, because the destabilized particles will build aggregates in the filter bed as the destabilized suspension passes through the media and the particles impinge and adhere to the media or trapped suspended matter. Large aggregates blind the filter resulting in short filter cycles.

PROPOSED CHEMICAL AND BIOLOGICAL DESTABILIZATION MODELS

Anionic polyelectrolytes are frequently used to flocculate negatively charged colloidal systems. Even better acknowledged is the capability of the activated sludge process to flocculate negatively charged sewage and industrial colloidal systems; an extreme case being the Contact Stabilization variation of the activated sludge process. Because the activated sludge mass and the anionic polyelectrolytes are both negatively charged, both of these destabilization examples seem to be counter to theory. A possible explanation for these extremely valuable properties lies in their electrical characteristics and the environment in which they operate.

Electrical Characteristics of Polyelectrolytes[18]

As discussed previously, ionizable groups on the polyelectrolyte are the source of an electric field. An especially unique property of polyelectrolytes is that the bound counterions in the potential tunnel

Table 32. DIMENSIONS INVOLVED IN COLLOID CHEMISTRY

A. Some Colloidal Systems (Diameters)	Angstroms
Color Bodies	50 - 1,000
Inert Colloids (clay, silt, inorganic salts, etc.)	1,000 - 30,000
Emulsions	2,000 - 100,000
Bacteria	5,000 - 100,000
Algae	50,000 - 8,000,000
B. Cations (Diameters)	
Na^+	1.9
Ca^{++}	2
Mg^{++}	1.3
Al^{+++}	1
C. Polyelectrolytes	
Potential Tunnel (Diameter)	7 - 11
Chain Length, 100,000 - 15,000,000 M.W.	250,000 - 40,000,000
D. Electrical Double Layer (Thickness)	
Range of Expected Values (Figure 4)	5 - 100
Expected Typical in Refinery	30
E. Solvent (Diameter)	
H_2O	4

area can move parallel to the polyelectrolyte molecule in the apparent volume occupied by the potential tunnel; thus, counterions can "flow" in the potential tunnel areas of Figures 54 and 55 analogous to water in a garden hose. Polyelectrolyte solutions, therefore, show an extremely large dielectric constant.

The dielectric constant or polarizability of polyelectrolytes is determined by the volume of polyelectrolyte in which counterions are retained (not by the charge density of the polyelectrolyte) as long as a region of bound but mobile counterions is formed. The dielectric increment depends on the geometry of the polyelectrolyte; extended polyelectrolytes give much larger dielectric increments than polyelectrolytes in the random coil conformation. Further, the dielectric increment of polyelectrolytes in the extended (or helix) conformation increases rapidly with increasing length. Uniform and continuous distribution of charged groups and the mobility of bound counterions are essential for large polarizability.[17]

Polyelectrolyte Destabilization Model

The means for negatively charged polyelectrolytes to destabilize negatively charged colloids is hypothesized to lie in the electrical properties of the polyelectrolyte. The proposed model in Figure 57 illustrates, approximately to scale, the colloid, its electrical double layer, the anionic polyelectrolyte, and its potential tunnel. Counterions are cations in both cases.

Cations in the double layer are subject to at least two opposing electrical forces, coulombic attraction to the colloid particle and, also, to the solvent to maintain an electrically balanced system.

When the sphere of influence of the anionic polyelectrolyte approaches the electrical double layer of the colloid, repulsion due to encountering like charges might be expected. However, in this instance, apparently:

1. The polyelectrolyte's electrical sphere of influence shields the counterions in a localized area of the colloid double layer from the attractive, electrical solvent forces.

2. The resulting electrical imbalance results in an increase in the negative coulombic potential in the localized, shielded area on the colloid.

3. The increase in negative coulombic potential attracts the mobile counterions from the potential tunnel region of the polyelectrolyte.

4. The potential tunnel of the polyelectrolyte serves as a conduit for counterions which neutralize the surface charge in the localized area of the colloid surface.

5. The charge neutralization achieved reduces the energy of repulsion at the localized site sufficiently so that the sum of the energy of repulsion and energy of attraction curves yields an interaction energy of attraction at the localized site (Figures 57 and 58).

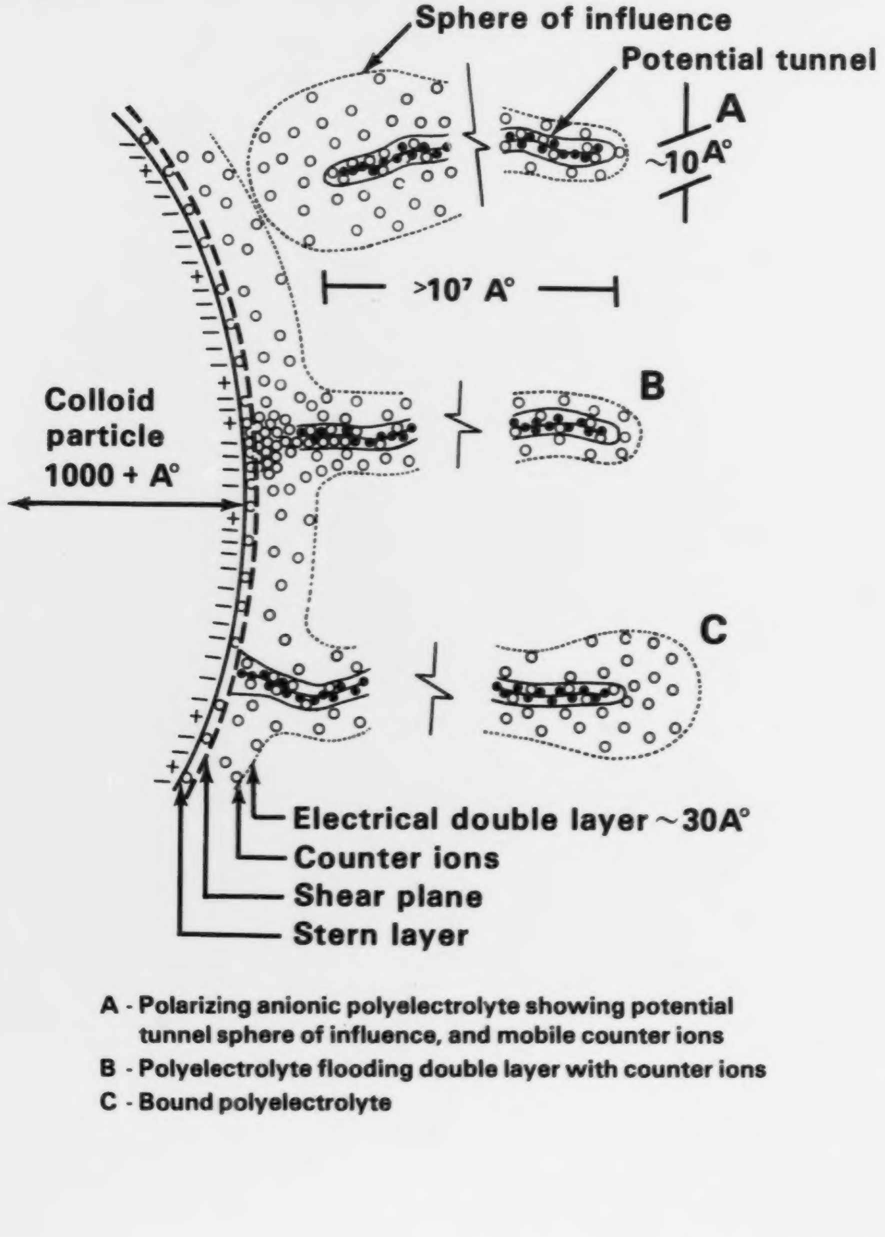
6. The positive interaction energy at the localized site permits attractive forces at the primary or secondary minimums between the polyelectrolyte and colloid to react.

The key to this hypothetical model is the mechanism by which the anionic polyelectrolytes implement the initial shielding action of the colloid surface from the electrical solvent forces. This capability lies in the special properties of the polyelectrolyte: polarizability, bound but mobile counterions in the potential tunnel, and equilibria between counterions in the potential tunnel and sphere of influence established by coulombic forces.

Repulsion due to like coulombic charge is illustrated in Figure 58. In Figure 58A, the double-layer overlap for energy of repulsion curves A (polyelectrolyte) and B (colloid) results in a net repulsion indicated by curve C. If this were a system of lyophobic colloids, it would be a stable colloidal system. Polyelectrolytes are extremely polarizable, however, particularly the high molecular weight anionics. The polarizing anionic polyelectrolyte can supply an essentially infinite quantity of counterions via its potential tunnel to a localized site near a colloid particle. This influx of counterions reduces the repulsion energy curve A by double-layer repression because of the equilibria established by the bound mobile counterions, and the reactants can approach more closely as shown in Figure 58B. The influx of counterions to the localized, charged region between the polyelectrolyte and colloid surface also would be expected to reduce the energy of repulsion (curve B) for the colloid in the localized region. The distance between the charged surfaces can be diminished further for this additional reason as illustrated in Figure 58C.

Figure 57

Electrical model for destabilization of negative colloid with anionic polyelectrolyte


Sphere of influence
Potential tunnel
A
~10A°
>10⁷ A°
B
Colloid particle 1000 + A°
C
Electrical double layer ~30A°
Counter ions
Shear plane
Stern layer

A - Polarizing anionic polyelectrolyte showing potential tunnel sphere of influence, and mobile counter ions

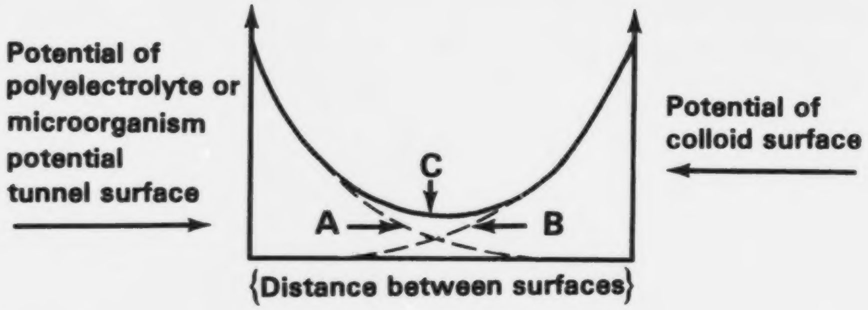
B - Polyelectrolyte flooding double layer with counter ions

C - Bound polyelectrolyte

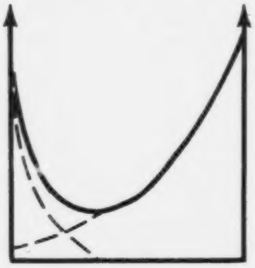
Figure 58

Polarization affects distance between surfaces

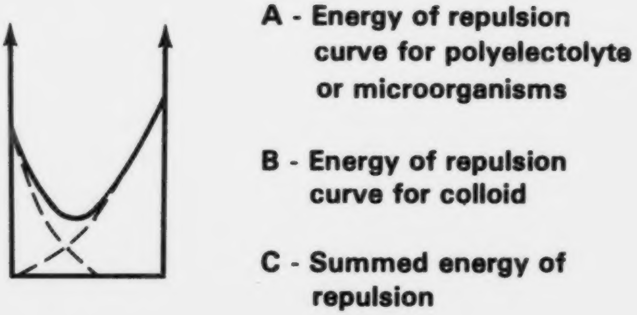
A. Stable colloid system


Potential of polyelectrolyte or microorganism potential tunnel surface
Potential of colloid surface
C
A
B
{Distance between surfaces}

B. Polarizing polyelectrolyte or bacteria systems



C. Double layer repressions by influx of counter-ions


A - Energy of repulsion curve for polyelectolyte or microorganisms
B - Energy of repulsion curve for colloid
C - Summed energy of repulsion

Interaction is achieved at shielded, localized sites if the counterions reduce the energy of repulsion curves such that the energy of interaction curve provides for a secondary minimum (see Figures 31 and 32). Larger particles readily flocculate. The more mobile, smaller-sized colloid particles are repelled and move away from similarly charged electrical regions. Further reduction in the energy barrier of the repulsive energy maximum by charge neutralization permits flocculation of the finer colloid particles.

Sterically, therefore, when the two electrical regions approach closely as illustrated in Figure 58C, the polyelectrolyte provides a shielding or insulating effect to the localized colloid site from the coulombic solution forces. Negating the effect of solution forces: results in an increase in attraction of counterions to the shielded, localized colloid site; contributes further to polyelectrolyte polarization, which increases the shielding effect; and causes an increased influx of counterions which results in increased double-layer charge repression at the site.

Electrical Characteristics of Microorganisms

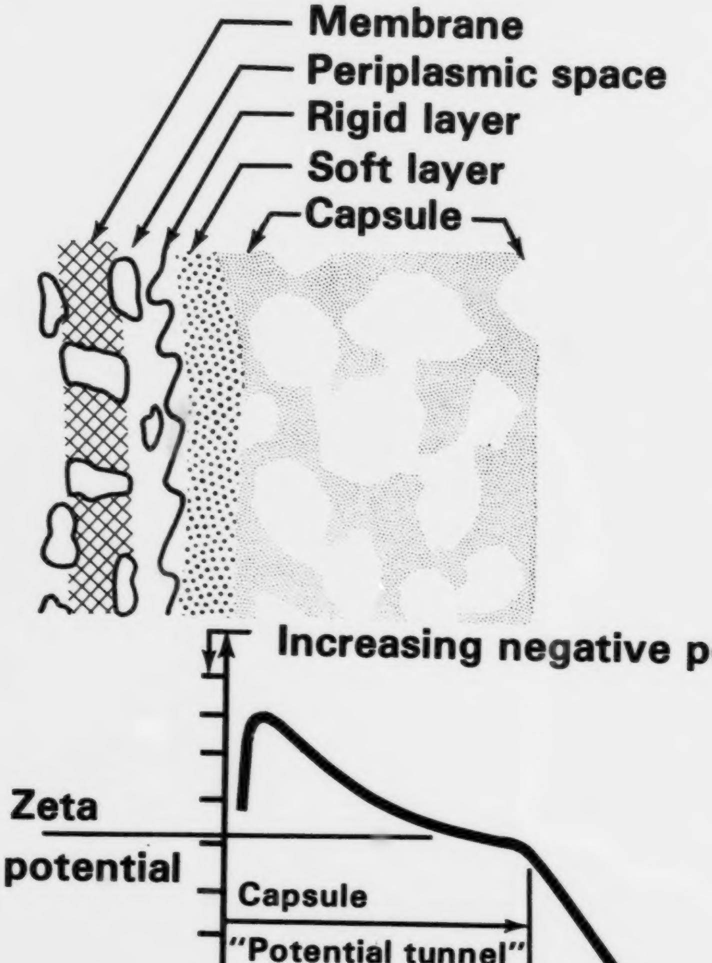
The microorganisms constituting activated sludge also have a negative zeta potential. Glucuronic acid has been proposed as the source of the electrical charge.[19]

As shown in Figure 59, the outermost surface of most bacteria is a slimy capsule varying in thickness up to 100,000+ A^o. The capsule composition varies with species and may consist of polymers of glucose or other sugars, amino and acid sugars, or polypeptides. Capsules generally consist of about 98 per cent water. The function of the capsular layer is proposed as serving the microorganisms as an osmotic barrier; i.e., a mechanism for guarding against too rapid an influx or efflux of water.[20] We propose that the capsular layer performs an equally if not more important function of providing the potential tunnel region.

The zeta potential is the charge difference between the plane of shear and the solution. In the case of microorganisms, the shear plane is some small but indeterminate distance beyond the outer boundary of the capsule. It is hypothesized that the region beyond the shear plane is analogous to the diffuse layer of counterions in the colloid double-layer model (Figure 30), whereas the capsule on the capsule side of the shear plane serves a function analogous to the potential

Figure 59

Activated sludge floc potential model


Membrane
Periplasmic space
Rigid layer
Soft layer
Capsule
Increasing negative potential
Zeta potential
Capsule
"Potential tunnel"
Distance

tunnel region of polyelectrolytes; i.e., it provides for a region of bound but mobile counterions. The acidic polysaccharides in the outer layer of the soft layer are at least partially responsible for the negative, electric charge on the bacteria surface. As in the polyelectrolyte example, mobile counterions establish an equilibria between the capsule layer (potential tunnel) and the solution and the bound counterions in the capsule layer can move parallel to the cell wall of the microorganism. The chief difference between the polyelectrolyte potential tunnel and the biological potential tunnel (capsule) is the comparatively large volume of the capsule, a very desirable property.

Biological Destabilization Model

As for polyelectrolytes, the means for negatively charged microorganisms to destabilize negatively charged colloids also is hypothesized to lie in the electrical properties of the microorganisms. The model proposed for polyelectrolytes (Figure 57) is analogous to the model for the biological system. Once again, cations are counterions in both cases. Dimensionally, the activated sludge floc and the capsule volume are larger than the comparative volumes occupied by the polyelectrolyte and its potential tunnel at the very low concentrations of polyelectrolyte used (frequently much less than 1 mg/l). As the diffuse counterion layer of the double layers overlap (Figure 58A), compared to polyelectrolytes, the massive size of the microorganisms' floc more readily shields the counterions in the colloid double layer from coulombic solvent forces. The microorganisms supply counterions to satisfy the electrical imbalance from their potential tunnel (capsule). The localized increase in counterions reduces the energy of repulsion curve analogous to anionic polyelectrolytes and the particles flocculate.

APPLICATION OF WATER CHEMISTRY PRINCIPLES

In a joint Environmental Protection Agency project entitled Chemical Coagulation/Mixed-Media Filtration of Aerated Lagoon Effluent (EPA-660/2-75-025),[15] it was found that, if maximum filtration efficiency was to be achieved, the intrinsic, negative zeta potential on the waterborne, suspended debris must be reduced or they will be repulsed by the negative electrical surface charge of the granular media and the filter effluent will be turbid.

Similarly to the negative surface charge on granular filter media, the surface of the flotation air bubbles is also negatively charged. Many of the residual organics in waste waters contain polar groups which cause them to exhibit surface activity. In refinery process water effluents, low surface tension is a manifestation of this situation. To exhibit surface activity, the organic molecules are viewed as consisting of two parts: one part has sufficient attraction for water to bring the entire molecule into solution, but the second part is rejected by water because the water molecules have more affinity for themselves than they do for this part of the organic molecule. If the forces rejecting this second part are strong enough, the organic molecules will tend to concentrate at an air-water interface and orient themselves such that at least part of the rejected part of the molecule is not in contact with the water phase. Thus, the polar functional groups will be oriented toward the water phase. Since the polar groups associated with organics are frequently oxygenated (carboxylic) or sulfonated (sulfonates, sulfates), their ionization in solution leaves them with a negative charge. When they collect at the air-water interface of flotation bubbles, they impart a negative charge to the flotation bubble. In the case of induced air flotation, for example, it has been determined that the most complete phase removal is achieved when the zeta potential of the dispersed phase is reversed to slight, positive values so that there is a net coulombic attraction to the air-water interface.[21]

Thus, there are parallels between the two unit operations used for phase removal, air flotation, and filtration. The means for providing for phase removal--air bubbles and granular filtration media--both have a negative electrical surface charge. Both unit operations fail to remove negatively charged colloids from water effectively. In a study of granular media filtration, maximizing filtration efficiency was found to require that the coulombic repulsive forces between the media surface and the colloid must be controlled.[15, 22] Controlling the colloid surface charge (zeta potential) was found to be readily achievable. In these studies, optimization of dissolved air flotation for phase removal was similarly found to be dependent on controlling the zeta potential of the suspended matter.

Determining Chemical Treatment Requirement for Destabilization

Waterborne colloids subject to chemical destabilization and phase separation fall into two general categories: relatively inert substances such as clays, sand, and organic materials; and microorganisms or biocolloids. Both categories of colloidal matter may be stabilized because they are charged and/or are highly hydrophilic. Both categories of colloidal matter also may vary in response to treatment by destabilization chemicals, and within each category, the state of subdivision may require additional consideration; i.e., extremely small colloidal particles are more difficult to destabilize. Typically, destabilization of biocolloids, such as are in aerated lagoon effluents, is a more demanding problem.

In the case of polyelectrolytes, some counterions at high concentrations screen the charged functional groups with an ionic cloud as previously described. Salinity, hydroxide, phenolics, sulfides, etc., are examples of the kind of counterions found to affect various cationics. Each waste water application of cationics must address the contaminants present if the most cost-effective polyelectrolyte is to be used.

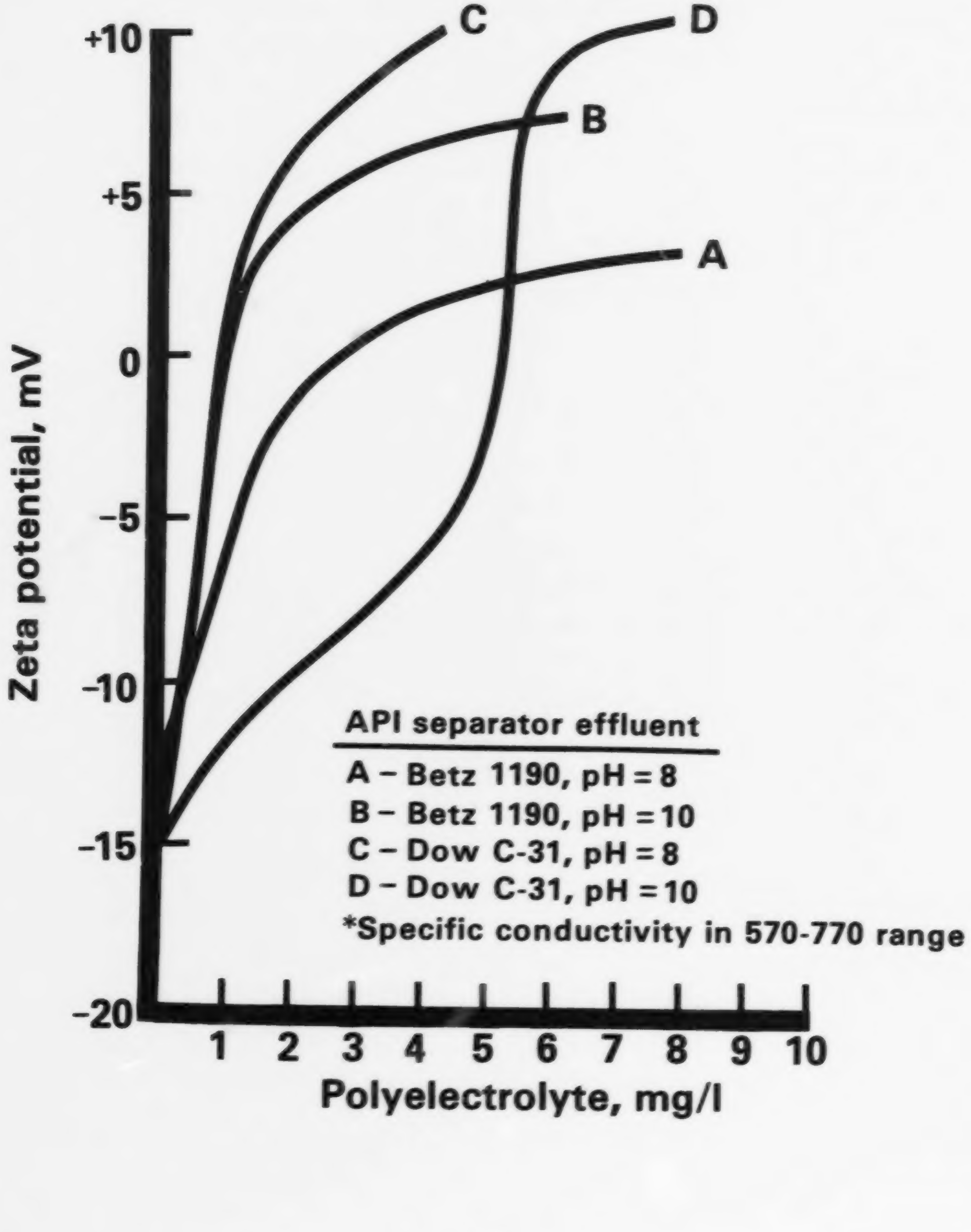
Titration Curves--

A comparison of polyelectrolyte performance and determination of antagonisms and synergisms is conveniently and quantitatively determined by use of ZP titration curves. Because the stability of a suspension is determined by the balance between the short-range (van der Waals) attractive forces and the repulsive coulombic forces between the particles (Figures 29 and 30), the objective of ZP-cationic polyelectrolyte titration curves is to quantify the amount of polyelectrolyte needed to reduce the repulsive coulombic forces to levels that permit total destabilization by attractive forces.

ZP titration curves were determined using the equipment of Riddick.[9] Increments of reagent are added to the water being investigated, mixed, and recirculated through the electrophoretic mobility cell for two minutes, and then the ZP determined. Plotting the data points yield ZP titration curves as in Figure 60 which show the effect of pH on the charge reversal properties of two good cationics. In this example, when compared to pH 8, the cationic 1190 is synergized and C-31 is antagonized at pH 10. The effects of pH and other potential antagonists and synergists are quantified by running titration curves in the presence of known amounts of the suspect substances.

Figure 60

Zeta potential — cationic polyelectrolyte titration curves of API separator effluent



The sensitivities of the two other good cationics to pH and phenol are shown in Figures 61 and 62. These data show that 431 is not significantly affected by phenol; however, phenol not only antagonizes 581 at a pH of 7.8, but overcomes a pH synergism and antagonizes 581 at a pH of 10.

Thus, by running titration curves, the effectiveness of cationic polyelectrolytes can be quantified for specific applications. The cationics in Table 33 are listed in order of the amount required to reach zero zeta potential.[23] This "end-point" is somewhat arbitrary, since many colloid systems are destabilized adequately for phase removal when the zeta potential is only reduced to -5 or -3 mV. This seems to depend on particle size and hydrophilicity.

Comparative rankings at these other "end-points" are also shown. A summary of polyelectrolyte synergisms and antagonisms to salinity, pH, and sulfides is shown in Table 34.

Compared to the relatively inert suspended matter which was the subject in Tables 33 and 34, biocolloids, being quite hydrophilic, can be more challenging a problem if tough, stable aggregates are required. Example ZP titrations for biocolloids in aerated lagoon effluent are shown in Figure 63.

Particle size and character (hydrophilic/hydrophobic) also impacts on destabilization. Consider the refinery problem of the aggregation of coke fines in hydraulic decoking water so they are readily removable. As shown in Figure 64, coke fines are originally stabilized by a negative ZP, but the negative charge is readily neutralized and reversed by cationic polyelectrolytes. One might think that too much cationic would simply restabilize the system as a positive colloid. However, using a cationic that has good bridging properties in addition to charge neutralization causes most of the solids to be enmeshed by the polymer. The larger size aggregates are more readily separable even though comparatively highly charged. As shown in Figure 64, addition of a small amount of high molecular weight weakly anionic polyelectrolyte to the positively charged cationic-treated coke particles will once again reverse the charge. Rather than redisperse the particles, however, the weakly anionic polymer efficiently "collects" the positively charged particles into massive aggregates easy to separate; i.e., once the high molecular weight

Figure 61

Sensitivity of cationic polyelectrolyte (Dearborn 431) to pH and Phenol

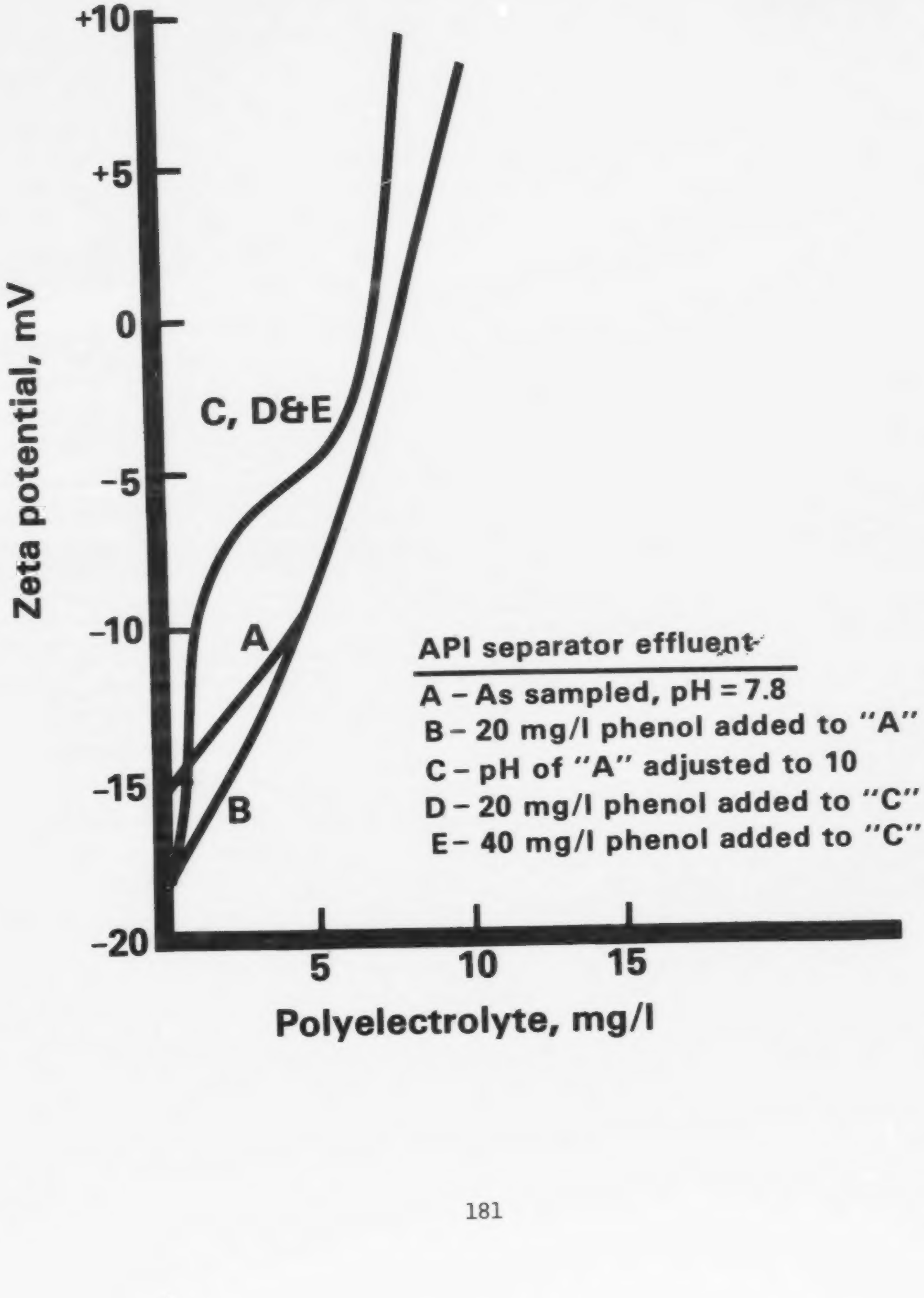


Figure 62

Sensitivity of cationic polyelectrolyte (Cyanamid 581) to pH and Phenol

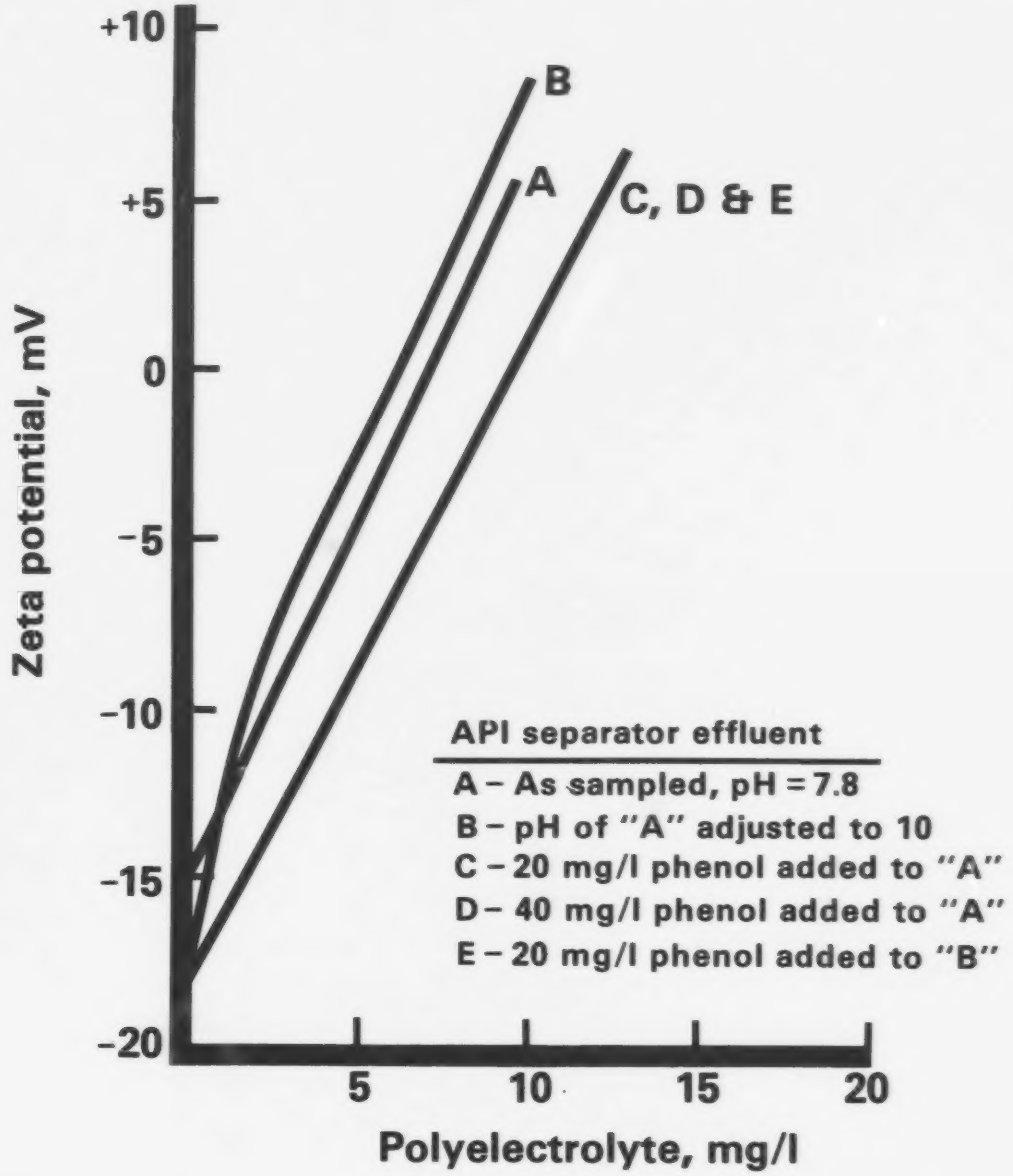


Figure 63

Titration of freshwater aerated lagoon effluent with cationic polyelectrolytes

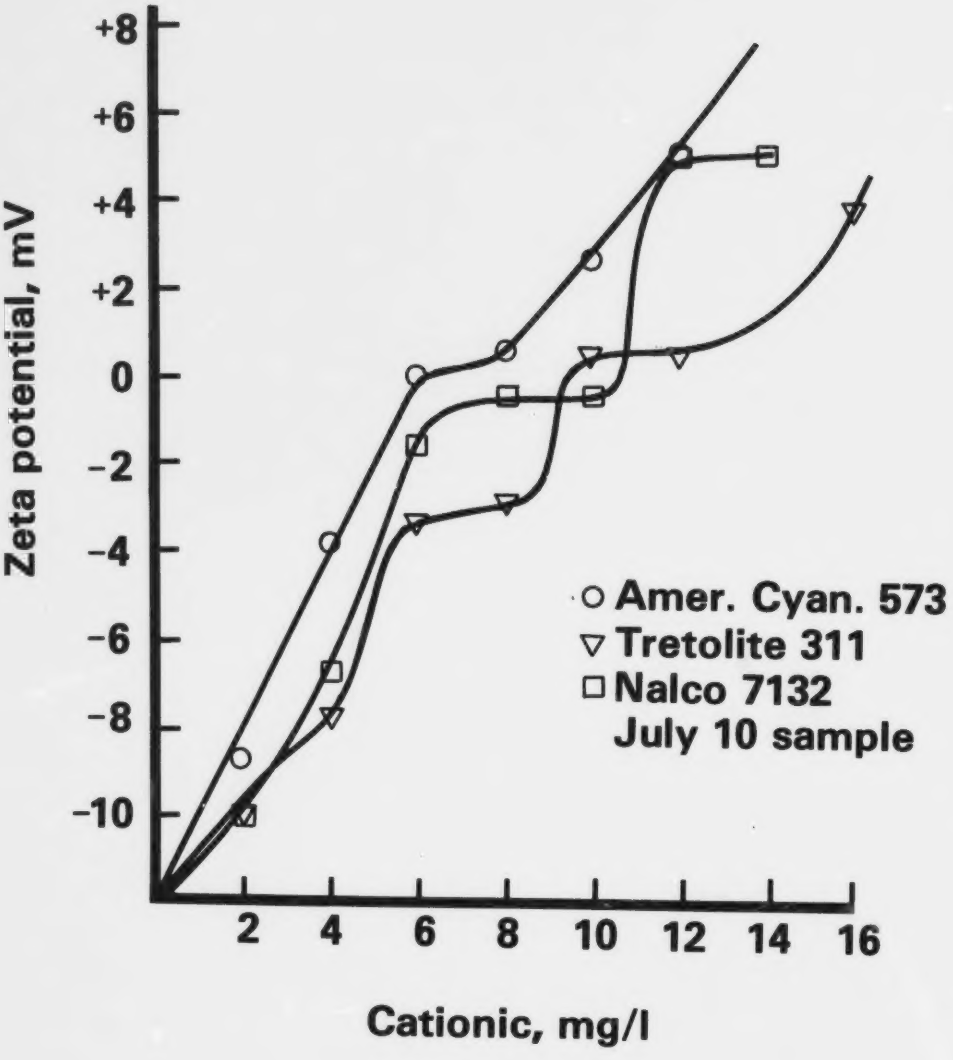
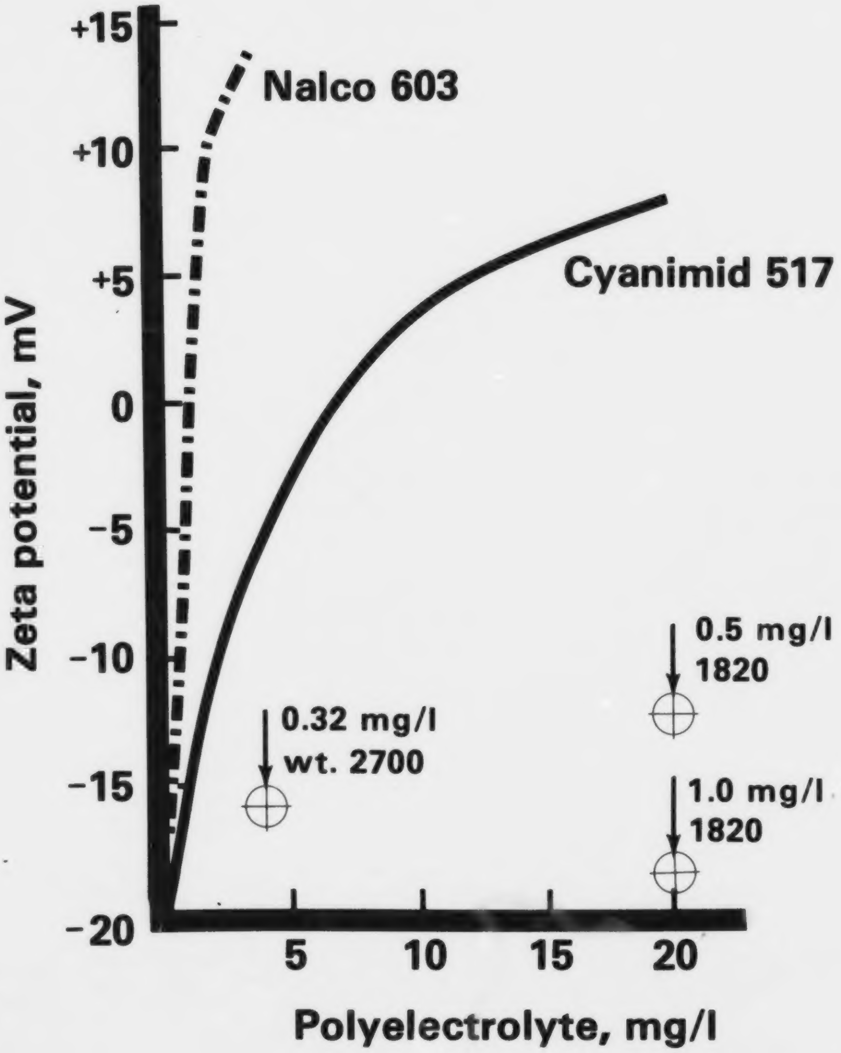


Figure 64

Zeta potential — cationic polyelectrolyte titration curves of coke fines in hydraulic decoking waters (pH = 7.6)



weakly anionic polymer establishes bonds with the solids and forms aggregates, the aggregates are bound together with strong enough forces to resist redispersion by hydraulic forces in a clarifier, filter, or DAF unit.[23]

In the course of running ZP-titration curves, the investigator is, in essence, also running the familiar "beaker tests." Valuable, additional information can also be obtained by simply making beaker observations as the titration proceeds. Two principal observations useful are the character (size and toughness) of the floc and the residual turbidity in the interstitial water.

For granular media filtration, a pinpoint, or microfloc, is desirable at zero ZP. This floc will penetrate and more fully load a granular media bed thereby maximizing filter run length. On the other hand, a large floc particle will form a "schmutzdecke" on the surface of the filter media thereby rapidly blinding the media and minimizing filter run lengths.

For dissolved air flotation, a large, tough floc correlates with best plant performance; a large, weak floc, with poorer performance. A weak floc may be consistent with inadequate chemical treatment such that flocculation at the secondary minimum (see Figures 31 and 32) prevails. When this weakly flocculated particle breaks up under the hydraulic stresses of the air flotation zone, many of the disaggregated particles may have sufficient residual negative charge that the capture and flotation efficiency by the negatively charged bubbles is poor.

An interesting and useful example of: (1) a large, but weak, floc, (2) the importance of particle size, and (3) destabilization of negatively charged solids by an anionic polyelectrolyte is the destabilization of raw sewage. The negatively charged raw sewage is dramatically flocculated by only 0.15 mg/l anionic polyelectrolyte of 15,000,000 molecular weight. However, the floc is weak, requires sedimentation procedures, and the residual turbidity is fairly high due to the fine colloid fraction which requires charge neutralization for destabilization.

The best microflocs are obtained using DMA/EPI-type cationics. If desired, for air flotation application, a DMA/EPI destabilized microfloc can be aggregated to large floc size by adding about 0.1 mg/l anionic polyelectrolyte. When filtering very cold water, below 50° F, through granular media filters at higher rates, a very small amount of anionic of about 0.01 mg/l is useful to discourage the scouring of solids from the bed by viscosity effects.

The best, large, tough flocs are obtained using certain quaternized polyacrylamides of high molecular weight. Multiple chemical systems are also useful: (1) the DMA/EPI cationic and anionic polyelectrolyte, (2) alum or iron salts and anionic polyelectrolyte, and (3) alum-cationic-anionic combinations. Multiple chemical systems using primary coagulants typically generate much wetter sludges.

The fine colloid fraction can be an especially difficult challenge for some cationic polyelectrolytes to destabilize. Where especially good phase removal is desired, a combination of cationic polyelectrolyte and alum (or iron salts) is frequently superior.

Plant Tests

After finishing studies with granular media filters on river water, API separator effluents at four refineries, connate water from oil wells, aerated lagoon effluents, etc.; and determining that controlling the zeta potential was essential for optimizing the performance of granular media filtration, it was decided to test the response of the subject dissolved air flotation unit to the same approach. The measure of success was to achieve an effluent turbidity of ten Jackson Turbidity Units (JTU) or less.

This performance goal set for the plant air flotation unit was demonstrated achievable using the following chemical destabilization systems:

1. Three-chemical system

   a. Add 30 mg/l alum.

   b. Add enough DMA/EPI cationic to bring the zeta potential to at least -3mV (about 3 mg/l active ingredient).

   c. Add 0.4 mg/l anionic polyelectrolyte.

2. Two-chemical system

   a. Add 10-20 mg/l alum.

   b. Add enough high molecular weight cationic to bring the zeta potential to at least -3mV (About 0.75 mg/l active ingredient).

3. One-chemical system

   a. Add enough high molecular weight quaternized polyacrylamide type cationic polyelectrolyte to bring the zeta potential to at least -3mV (about 1.1 mg/l active ingredient).

Relation of Current Work To Initial Study

Current work indicates the erratic and poor AFU performance observed early in the initial study is related to two basic problems: the initial design of the unit as provided by the vendor and inconsistent and frequently inadequate chemical pretreatment.

Initial mechanical design problems discussed in SECTION VI can be partially compensated for by proper chemical destabilization, but proper mechanical design is a requirement if this unit operation is to be optimized. Thus, chemical destabilization is not a substitute for proper design, and it is misleading to describe how proper chemical destabilization of waste water yielded an improvement in performance of poorly designed facilities. It is only of significance to report how proper chemical destabilization improved the performance of an adequately designed unit.

The investigation of process variables reported in SECTION VII was conducted after most of the design modifications were installed. There were extended periods of excellent operation during this lengthy test period; however, periods of erratic performance were encountered. A major contributor to erratic performance is inadequate chemical destabilization. If this variable is controlled, much improved AFU performance is obtained. The chemical destabilization variable must be fixed if a reliable relationship is to be obtained with the various process variables: recycle rate; recycle air volume; chemical addition, mixing, and flocculation; comparison of coagulants and flocculants; effect of skimmer speeds; overflow rates; Reynolds Number effects; water content of air-floated scum, etc.

Fortunately, after process modifications, the available operating process variables provided desired effluent quality goals when chemical destabilization with a zeta potential charge neutralization goal of at least -3mV was observed.

The original investigators made much of "difficult-to-treat feed" and "easy-to-treat feed" (Tables 8 through 11) and related the presence of sulfonate-type soaps to feed treated with difficulty. Subsequent work demonstrated chlorides interferes with alum coagulation,[15] and sulfides, phenolics, hydroxide, and chlorides react with various cationic polyelectrolytes (page 178 et seq. and Tables 33, 34, and 35). Zeta potential measurements were found to be a powerful tool to detect and quantify the antagonisms and synergisms of these interfering substances.

It is expected that sulfonate-type substances could interfere with destabilization chemicals.

The mechanisms could include: (1) adsorption on the colloids, lowering their ZP, thereby requiring more coagulant for charge neutralization (although intensity of charge does not necessarily relate to quantity); (2) forming a chemical bond with the cationic polyelectrolyte's functional group thereby negating its electrical charge effects; (b) sterically hindering the approach of colloid surfaces to the site for reaction; or (3) anion penetration of the hydrolyzing alum wherein the olation of alum to transient cationic polymers is impaired (page 146). The fact that the origin of the sulfonates was from batch operations, and that most of the sulfonates were not dissolved but adsorbed on the solids and their functionality not fully recognized, led to variable observations by the original investigators.

A "difficult" or "easy" to treat feed was also possibly due to the state of subdivision and the kind of particles being removed. The larger the particles, the least the impact of electrical surface charge effects; the smaller the particle, the more the impact. The more fine biocolloids, the more troublesome the destabilization; the more the inert fraction, the easier the destabilization.

The flocculating mechanism occurring may be due to the attraction at the secondary minimum (Figures 31 and 32) because of inadequate charge neutralization. Such agglomerates are bound by weak forces

Table 33. THE COMPARATIVE EFFECTIVENESS OF CATIONIC POLYELECTROLYTES FOR CHARGE NEUTRALIZATION OF SUSPENDED MATTER IN API SEPARATOR EFFLUENTS AS DETERMINED BY ZETA POTENTIAL TITRATION CURVES

Conditions	Polyelectrolyte[a, b]	mg/l To Achieve Indicated ZP Equipment				Rank at Indicated ZP Endpoint			
		-5	-3	0	+3	-5	-3	0	+3
A. pH = 8; Specific Cond. = 560, and Zero Sulfides.	C-31	.25	.5	.5	1	1	1	1	1
	581	.5	1	1.25	3.75	2	2	2	5
	431	1.5	1.75	2.5	3	6	4	3	2
	7132	1.25	1.75	2.5	3.25	5	4	3	3
	1180	1.5	2	2.5	3	6	5	3	2
	1190	1	1.5	3	6	4	3	4	8
	2860	2.5	2.75	3	3.25	8	6	4	4
	2870	2.25	2.75	3.25	3.75	7	6	5	5
	863	.75	1	3.25	6.75	3	2	5	9
	7134	2.5	3	3.75	4.5	8	7	6	6
	2640	2.25	3	4	4.5	7	7	7	6
	751	2.25	3	4	5	7	7	7	7
	FA	2.5	3.25	4	5	8	8	7	7
	864	5.25	7	10	c	9	9	8	10
	860	6.75	7.25	c	c	10	10	9	10
B. pH = 9.8; Specific Cond. = 680; and Zero Sulfides.	1180	1	1.25	1.5	2	1	1	1	1
	1190	1	1.25	1.5	2	1	1	1	1
	581	1	1.5	2	2.75	1	3	2	2
	7132	1	1.25	2	3.5	1	2	2	3
	2870	1.75	2.25	3	3.5	2	3	3	3
	2860	2.25	2.5	3	3.5	3	4	3	3
	863	1.75	2.25	3.5	4.75	2	3	4	4
	431	3	3.5	4+	4.75	5	5	5	4
	751	2.5	3.5	4.5	5.25	4	5	6	5
	C-31	4.25	4.5	4.75	5.25	7	6	7	5
	2640	5	5.5	6	6.5	8	8	8	6
	7134	4	4.75	6	7.25	6	7	8	7
	FA	3	4.5	6.5	c	5	6	9	8
C. pH = 10; Specific Cond. = 4,100; and Zero Sulfides.	2870	2	2.75	4	5.25	1	1	1	2
	431	3	3.75	4.5	5	3	3	2	1
	751	2.5	3.5	5	6.75	2	2	3	3
	581	4	4.75	5.75	6.75	4	4	4	3
	2860	5	6	6.5	7.5	5	5	5	4
	7132	5	6	7.25	9	5	5	6	5
	2640	6.5	7.25	10	c	6	6	7	6
	863	7	8.5	10	c	7	7	7	6
	C-31	4	c	c	c	4	8	8	6

a. C-31 (Dow); 581 (Cyanamid); 431 (Dearborn); 7132 (Nalco); 1180, 1190 (Betz); 2860, 2870, 2640 (Calgon); 860, 863, 864 (Hercules); 751 (Mazer); and FA (BASF Wyandotte).

b. Arranged in order of performance using zero ZP as endpoint.

c. Indicated ZP not achieved.

Table 34. POLYELECTROLYTE SYNERGISMS AND ANTAGONISMS TO SALINITY, pH, AND SULFIDES IN API SEPARATOR EFFLUENTS

Conditions	Polyelectrolyte	mg/l of Polyelectrolyte Required to Reach Zero Zeta Potential at Indicated Specific Conductance (b) 680	4,100	11,000
A. Sensitivity to Salinity (Salt) at pH = 10	1180	1.25	a	6
	7132	2.25	7	3.75
	581	3	5.75	4
	2860	3	7	3.25
	2870	3	5	2.75
	863	3.75	a	a
	431	5	4.25	3
	751	5	6.25	4
	C-31	5	a	a
	2640	6.5	a	3.75

	Polyelectrolyte	mg/l of Polyelectrolyte for Zero Zeta Potential at pH = 8	pH = 10	mg/l Increase or Decrease (-) at pH = 10
B. Sensitivity to pH. Specific Conductance = 570 to 770	C-31	1	5	4
	581	1.75	3	1.25
	7132	2.75	2.25	-.5
	431	3	5	2
	2860	3	3	0
	2870	3	3	0
	1180	3	1.25	-1.75
	1190	3.25	1.25	-2
	7134	4.5	5.5	1
	751	4.5	5	.5
	2640	4.5	6.5	2
	FA	4.5	10	5.5
	863	5	3.75	-1.25

	Polyelectrolyte	mg/l Polyelectrolyte for Zero Zeta Potential at 0 mg $S^{=}$/1	16 mg $S^{=}$/1	8 mg $S^{=}$/1
C. Sensitivity to Sulfides at pH = 8 to 8.2. Specific Conductance = 720	581	1.75	14	10
	7132	2.75	14.5	a
	431	3	14	a
	2860	3	16	a
	1180	3	20	a

a. Not determined.

b. Specific Conductance in micromhos. 4,100 SC = 1.2 gm NaCl/1; 11,000 SC = 3.5 gm NaCl/1.

Table 35. THE COMPARATIVE EFFECTIVENESS OF CATIONIC POLYELECTROLYTES FOR CHARGE NEUTRALIZATION OF BIOCOLLOIDS IN AERATED LAGOON EFFLUENT (pH = 7.5, SP. COND. = 720)

Polyelectrolyte[a]	mg/l To Achieve Indicated ZP Endpoint				Rank at Indicated ZP Endpoint			
	-5	-3	0	+3	-5	-3	0	+3
581	5	6	7.25	9.25	1	1	1	2
431	6.5	6.75	7.25	7.75	3	3	1	1
C-31	5.25	6.25	8.75	10	2	2	2	3
1180	7	8.25	10	b	4	5	3	4
2860	8.5	9.25	10	b	5	6	3	4
2870	7	7.5	b	b	4	4	4	4
2640 (c)	b	b	b	b	6	7	4	4

a. Arranged in order of performance using zero ZP as endpoint.

b. Indicated ZP not achieved.

c. While 2640 exhibited very poor charge neutralization capacity for biocolloids, its bridging properties were very good and it would be fairly effective when clarifiers or DAF units are used.

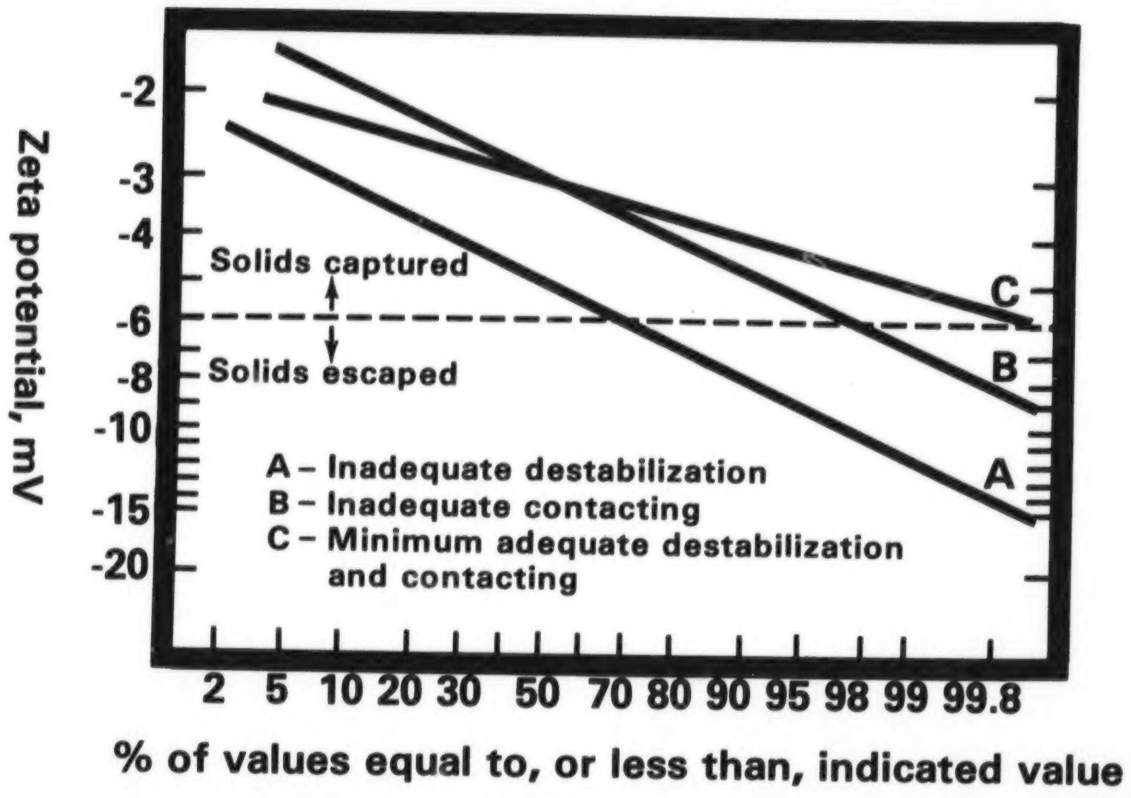
and readily redisperse when subject to flotation, and many fines escape in the effluent. Thus, the flocculating mechanisms occurring may lead to the description of a "hard-to-treat feed."

The aforementioned interferences to effective air flotation may be effectively eliminated by first destabilizing the colloid/solids system to, at least, -3mV zeta potential. Our current level of experience indicates the double-layer energy barrier (Figures 31 and 32) is overcome, and the stronger binding forces at the primary minimum react.

Reported zeta potential readings are usually averages of at least ten values. Average or median ZP values can be very misleading when used as a measure of destabilization effectiveness; the key is the ZP probability distribution. As an example of principle, consider the three ZP probability distribution curves in Figure 65. For this water, the air flotation unit can capture those particles with a ZP less than about -6mV and those with a negative ZP greater than -6mV escape. Thus, the sample of curve A having a median ZP of -5mV is inadequately destabilized because 30 per cent of the solids are more negatively charged than -6mV and escape the air flotation unit. The sample of curve B has more chemical added, and the median ZP is -3mV; a difference of 2mV from curve A. More important though is the fact that only 2 per cent of the solids are more negatively charged than -6mV ZP compared to 30 per cent for curve A. Comparing the probability slopes for curves A and B shows the importance of good mixing and flocculating design; although the median ZP values are identical, the flatter probability curve for Sample C is illustrative of better designed facilities than the steeper, more undesirable slope for Sample B. Thus, conditions that impact on the probability distribution such as nature of the destabilization chemicals used, mixing, flocculation, etc., must not be ignored, and the target median ZP selected reflect the shortcomings of the system. For poor system design, more chemical usage is needed to achieve improved performance. For extreme cases of high hydraulic overloads and solids burden, a three-chemical system, where alum and cationic is used to charge reverse the system to positive ZP values and then 0.2 to 0.5 mg/l weakly anionic polyelectrolyte used to flocculate the solids to large, very tough aggregates, will overcome many system shortcomings and provide excellent effluent quality.

Figure 65

Zeta potential probability distribution of adequate and inadequate destabilization systems



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GLOSSARY, ABBREVIATIONS, AND CONVERSION FACTORS

GLOSSARY

Aerated lagoon--A natural or artificial waste water treatment lagoon (generally from 4 to 12 feet deep) in which mechanical or diffused-air aeration is used to supplement the oxygen supply.

Biological treatment processes--Means of treatment in which bacterial or biochemical action is intensified to stabilize, oxidize, and nitrify the unstable organic matter present. Trickling filters, activated sludge processes, and lagoons are examples.

Combined sewage--Sewage containing both domestic sewage and surface water or storm water, with or without industrial wastes. Includes flow in heavily infiltrated sanitary sewer systems as well as combined sewer systems.

Combined sewer--A sewer receiving both intercepted surface runoff and municipal sewage.

Combined sewer overflow--Flow from a combined sewer in excess of the interceptor capacity that is discharged into a receiving water.

Detention--The slowing, dampening, or attenuating of flows either entering the sewer system or within the sewer system by temporarily holding the water on a surface area, in a storage basin, or within the sewer itself.

Dilution ratio--The ratio of the quantity of combined sewer overflow or storm sewer discharge to the average quantity of diluting water available after initial mixing at the point of disposal or at any point under consideration.

Disinfection--The art of killing the larger portion of microorganisms in or on a substance with the probability that all pathogenic bacteria are killed by the agent used.

Domestic sewage--Sewage derived principally from dwellings, business buildings, institutions, and the like. It may or may not contain ground water.

Dual treatment--Those processes or facilities designed for operating on both dry- and wet-weather flows.

Dynamic regulator--A semiautomatic or automatic regulator device which may or may not have movable parts that are sensitive to hydraulic conditions at their points of installation and are capable of adjusting themselves to variations in such conditions or of being adjusted by remote control to meet hydraulic conditions at points of installation or at other points in the total combined sewer system.

Equalization--The averaging (or method for averaging) of variations in flow and composition of a liquid.

First flush--The condition, often occurring in storm sewer discharges and combined sewer overflows, in which a disproportionately high pollutional load is carried in the first portion of the discharge or overflow.

Industrial waste waters--The liquid wastes from industrial processes, as distinct from domestic sewage.

Infiltrated municipal sewage--That flow in a sanitary sewer resulting from a combination of municipal sewage and excessive volumes of infiltration/inflow resulting from precipitation.

Infiltration--The water entering a sewer system and service connections from the ground, through such means as, but not limited to, defective pipes, pipe joints, connections, or manhole walls. Infiltration does not include, and is distinguished from, inflow.

Infiltration ratio--The ratio of rainfall volume entering the sewers to the total rainfall volume.

Inflow--The water discharged into a sewer system and service connections from such sources as, but not limited to, roof leaders, cellar, yard, and area drains, foundation drains, cooling water discharges, drains from springs and swampy areas, manhole covers, cross connections from storm sewers and combined sewers, catch basins, storm waters, surface runoff, street wash waters, or drainage. Inflow does not include, and is distinguished from, infiltration.

In-system--Within the physical confines of the sewer pipe network.

Intercepted surface runoff--That portion of surface runoff that enters a sewer, either storm or combined, directly through catch basins, inlets, etc.

Interceptor--A sewer that receives dry-weather flow from a number of transverse combined sewers and additional predetermined quantities of intercepted surface runoff and conveys such waters to a point for treatment.

Municipal sewage--Sewage from a community which may be composed of domestic sewage, industrial wastes, or both.

Nonsewered urban runoff--That part of the precipitation which runs off the surface of an urban drainage area and reaches a stream or other body of water without passing through a sewer system.

Overflow--(1) The flow discharging from a sewer resulting from combined sewage, storm waste water, or extraneous flows and normal flows that exceed the sewer capacity. (2) The location at which such flows leave the sewer.

Oxidation pond--A basin (generally 2 to 6 feet deep) used for retention of waste waters before final disposal, in which biological oxidation of organic matter is effected by natural or artificially accelerated transfer of oxygen to the water from air.

Physical-chemical treatment processes--Means of treatment in which the removal of pollutants is brought about primarily by chemical clarification in conjunction with physical processes. The process string generally includes preliminary treatment, chemical clarification, filtration, carbon adsorption, and disinfection.

Physical treatment operations--Means of treatment in which the application of physical forces predominates. Screening, sedimentation, flotation, and filtration are examples. Physical treatment operations may or may not include chemical additions.

Plug flow--The passage of liquid through a chamber such that all increments of liquid move only in the direction of flow and at equal velocity.

Pollutant--Any harmful or objectionable material in or change in physical characteristic of water or sewage.

Pretreatment--The removal of material such as gross solids, grit, grease, and scum from sewage flows prior to physical, biological, or physical-chemical treatment processes to improve treatability. Pretreatment may include screening, grit removal, skimming, preaeration, and flocculation.

Regulator--A structure which controls the amount of sewage entering an interceptor by storing in a trunk line or diverting some portion of the flow to an outfall.

Retention--The prevention of runoff from entering the sewer system by storing on a surface area or in a storage basin.

Sampling train--The intake, method for gathering, and transporting, tubing, and storage container of a sewer flow sampler.

Sanitary sewer--A sewer that carries liquid and water-carried wastes from residences, commercial buildings, industrial plants, and institutions, together with relatively low quantities of ground, storm, and surface waters that are not admitted intentionally.

Sewer--A pipe or conduit generally closed, but normally not flowing full, for carrying sewage or other waste liquids.

Sewerage--System of piping, with appurtenances, for collecting and conveying waste waters from source to discharge.

Static regulator--A regulator device which has no moving parts or has movable parts which are insensitive to hydraulic conditions at the point of installation and which are not capable of adjusting themselves to meet varying flow or level conditions in the regulator-overflow structure.

Storm flow--Overland flow, sewer flow, or receiving stream flow caused totally or partially by surface runoff or snowmelt.

Storm sewer--A sewer that carries intercepted surface runoff, street wash and other wash waters, or drainage, but excludes domestic sewage and industrial wastes.

Storm sewer discharge--Flow from a storm sewer that is discharged into a receiving water.

Storm water--Water resulting from precipitation which either percolates into the soil, runs off freely from the surface, or is captured by storm sewer, combined sewer, and to a limited degree, sanitary sewer facilities.

Surcharge--The flow condition occurring in closed conduits when the hydraulic grade line is above the crown of the sewer.

Surface runoff--Precipitation that falls onto the surfaces of roofs, streets, ground, etc., and is not absorbed or retained by that surface, thereby collecting and running off.

Trickling filter--A filter consisting of an artificial bed of coarse material, such as broken stone, clinkers, slate, slats, brush, or plastic materials, over which sewage is distributed or applied in drops, films, or spray from troughs, drippers, moving distributors, or fixed nozzles, and through which it trickles to the underdrains, giving opportunity for the formation of zoogloeal slimes which clarify and oxidize the sewage.

Urban runoff--Surface runoff from an urban drainage area that reaches a stream or other body of water or a sewer.

Waste water--The spent water of a community. See Municipal Sewage and Combined Sewage.

ABBREVIATIONS

Organizations

APWA	American Public Works Association
ASCE	American Society of Civil Engineers
DMWS	Detroit Metropolitan Water Service
EPA	U.S. Environmental Protection Agency
MSDGC	Metropolitan Sanitary District of Greater Chicago
NPDES	National Pollution Discharge Elimination System
NSF	National Science Foundation
OWRR	Office of Water Resources Research
RD&D	Research, Development, and Demonstration Program (EPA)
USPHS	U.S. Public Health Service

Symbols

%	per cent
$	dollar
°C	degree(s) Celsius (Centigrade)
∼	approximately
>	greater than
<	less than
≥	greater than or equal to
≤	equal to or less than

¢	cents
/	per
ABS	acrylonitrile butadiene styrene
AFU	air flotation unit
API	American Petroleum Institute
avg	average
BFU	bioflotation unit
BOD_5	biochemical oxygen demand (5-day)
cf or cu ft	cubic foot (feet)
cfs	cubic feet per second
cf/lb	cubic feet per pound
cm	centimeter(s)
cm/hr	centimeter(s) per hour
cm/yr	centimeter(s) per year
COD	chemical oxygen demand
CPVC	chlorinated polyvinylchloride
cu m	cubic meter(s)
cu m/day	cubic meter(s) per day
cu m/min/day	cubic meter(s) per minute per day
cu m/min/ha	cubic meter(s) per minute per hectare
cu m/min/100 l	cubic meter(s) per minute per 100 liters
cu m/sec	cubic meter(s) per second
cy	cubic yard

degree C	degree(s) Celsius (Centigrade)
degree F	degree(s) Fahrenheit
DO	dissolved oxygen
DWF	dry-weather flow
eff.	effluent
ENR	Engineering News-Record (index)
F/M	food-to-microorganism ratio
fpm	feet per minute
fps	feet per second
FRP	glass fiber-reinforced plastic
ft	foot (feet)
g	gram(s)
gal.	gallon(s)
gal./inch diameter/ mile/day	gallons per inch diameter per mile per day
gpd/sq ft	gallon(s) per day per square foot
gpm/sq ft	gallon(s) per minute per square foot
ha	hectare
hr/yr	hour(s) per year
HST	heat shrinkable tubing
in.	inch(es)
in./hr	inch(es) per hour

in./yr	inch(es) per year
JTU	Jackson turbidity unit
kg	kilogram(s)
kg/sq cm	kilograms per square centimeter
kl	kiloliter(s)
km	kilometer(s)
kwh	kilowatt hour(s)
lb	pound(s)
lb/day	pounds per day
lb/mil gal.	pounds per million gallons
lb/min	pound(s) per minute
lb/yr	pounds per year
l/day/ha	liter(s) per day per hectare
l/kg	liter(s) per kilogram
l/min/sq m	liter(s) per minute per square meter
l/sec	liter(s) per second
l/sec/sq m	liter(s) per second per square meter
m	meter(s)
max	maximum
mg	milligram(s)
mgad	million gallons per acre per day

mgd	million gallons per day
mg/l	milligrams per liter
mil gal.	million gallons
min	minute (s)
min	minimum
Ml	megaliter (s)
ml	milliliter (s)
MLSS	mixed liquor suspended solids
ml/l	milliliter (s) per liter
mm	millimeter (s)
MPN	most probable number
m/sec	meter (s) per second
N	nitrogen
NA	not available
N/A	not applicable
P	phosporus
pcf	pounds per cubic foot
ppm	parts per million
psf	pounds per square foot
psi	pounds per square inch
PVC	polyvinylchloride
PVDC	polyvinyldichloride

rpm	revolutions per minute
RRL	Road Research Laboratory
scfm	standard cubic feet per minute
sq cm	square centimeter (s)
sq ft	square foot (feet)
sq ft/mgd	square feet per million gallons per day
sq in.	square inch (es)
sq km	square kilometer (s)
sq mi	square mile (s)
sq m/cu m/sec	square meter per cubic meter per second
SS	suspended solids
STP	sewage treatment plant
SWMM	Storm Water Management Model
TOC	total organic carbon
TOD	total oxygen demand
TON	threshold odor number
TSS	total suspended solids
TVS	total volatile solids
VS	volatile solids
VSS	volatile suspended solids
yr	year (s)

CONVERSION FACTORS

English to Metric

English unit	Abbr	Multiplier	Abbr	Metric unit
acre	acre	0.405	ha	hectare
acre-foot	acre ft	1,233.5	cu m	cubic meter
cubic foot	cf	28.32	l	liter
cubic feet per minute	cfm	0.0283	cu m/min	cubic meters per minute
cubic feet per second	cfs	28.32	l/sec	liters per second
cubic inch	cu in	16.39	cu cm	cubic centimeter
		0.0164	l	liter
cubic yard	cy	0.765	cu m	cubic meter
		764.6	l	liter
degree Fahrenheit	deg F	0.555 (°F-32)	deg C	degree Celsius
feet per minute	fpm	0.00508	m/sec	meters per second
feet per second	fps	0.305	m/sec	meters per second
foot (feet)	ft	0.305	m	meter(s)
gallon(s)	gal	3.785	l	liter(s)
gallons per acre per day	gad	9.353	l/day/ha	liters per day per hectare
gallons per capita per day	gcd	3.785	l/capita/day	liters per capita per day
gallons per day	gpd	4.381 x 10^{-5}	l/sec	liters per second
gallons per day per per square foot	gpd/sq ft	1.698 x 10^{-3}	cu m/hr/sq m	cubic meters per hour per square meter
		0.283	cu m/min/ha	cubic meters per minute per hectare
gallons per minute	gpm	0.0631	l/sec	liters per second
gallons per minute per square foot	gpm/sq ft	2.445	cu/m/hr/sq m	cubic meters per hour per square meter
		0.679	l/sec/sq m	liters per second per square meter
gallons per square foot	gpsf	40.743	l/sq m	liters per square meter
horsepower	hp	0.746	kw	kilowatts
inch(es)	in.	2.54	cm	centimeter
inches per hour	in./hr	2.54	cm/hr	centimeters per hour
million gallons	mil gal.	3.785	Ml	megaliters (liters x 10^6)
		3,785.0	cu m	cubic meters
million gallons per acre per day	mgad	0.039	cu m/hr/sq m	cubic meters per hour per square meter
million gallons per day	mgd	43.808	l/sec	liters per second
		0.0438	cu m/sec	cubic meters per second
mile	mi	1.609	km	kilometer
parts per billion	ppb	0.001	mg/l	milligrams per liter
parts per million	ppm	1.0	mg/l	milligrams per liter
pound(s)	lb	0.454	kg	kilogram
		453.6	g	grams
pounds per acre per day	lb/acre/day	0.112	g/day/sq m	grams per day per square meter
pounds per day per acre	lb/day/acre	1.121	kg/day/ha	kilograms per day per hectare
pounds per 1,000 cubic feet	lb/1,000 cf	16.077	g/cu m	grams per cubic meter
pounds per million gallons	lb/mil gal.	0.120	mg/l	milligrams per liter
pounds per cubic foot	pcf	16.02	kg/cu m	kilograms per cubic meter
pounds per square foot	psf	4.882 x 10^{-4}	kg/sq cm	kilograms per square centimeter
pounds per square inch	psi	0.0703	kg/sq cm	kilograms per square centimeter
square foot	sq ft	0.0929	sq m	square meter
square inch	sq in.	6.452	sq cm	square centimeter
square mile	sq mi	2.590	sq km	square kilometer
square yard	sq yd	0.836	sq m	square meter
standard cubic feet per minute	scfm	1.699	cu m/hr	cubic meters per hour
ton (short)	ton	907.2	kg	kilograms
		0.907	metric ton	metric ton
yard	yd	0.914	m	meter

SECTION XVIII

APPENDIXES A THROUGH F

APPENDIX A

Table 1: RECYCLE TESTS AT 50 PSIG AIR SATURATION PRESSURE

Test No.	1		2		3		4		5		6	
Recycle Rate, GPM	800	500	800	500	800	500	800	1000	800	1000	800	1000
Feed Turbidity, JTU	32	34	42	32	31	28	35	28	28	25	32	32
Prod. Turbidity	4.5	8.5	7.5	13	4.5	11	6	8	9.5	4.5	5	6
% Reduction	86	75	82	59	85	61	83	71	66	82	84	81
Feed Oil, mg/l	41	35	52	45	41	47	75	34	36	26	38	36
Prod. Oil, mg/l	9	16	10	26	10	21	15	14	14	8	9	10
% Reduction	78	54	81	42	76	45	80	59	61	71	76	72
Feed Solids, mg/l	26	17	24	19	26	17	28	27	17	10	15	15
Prod. Solids, mg/l	8	14	12	13	8	15	11	16	12	8	5	5
% Reduction	69	18	50	32	69	12	60	41	29	20	67	67
Air/(Oil & Solids)	0.41	0.26	0.42	0.26	0.42	0.26	0.42	0.52	0.43	0.54	0.41	0.51
Water Flow, MGD	29	29	29	29	29	29	29	29	29	29	29	29
Alum mg/l	33	33	33	33	33	33	41	41	41	41	41	41
Polymer, mg/l	0.21	0.21	0.21	0.21	0.21	0.25	0.25	0.25	0.25	0.25	0.21	0.21
% Recycle	27	17	27	17	27	17	27	34	27	34	27	34
pH	7.6	7.5	7.3	7.4	7.7	7.4	7.4	7.4	7.1	7.1	7.6	7.3
Temp., ^{o}F	73	73	72	72	72	72	72	72	69	69	73	73
Sulfonates, mg/l	0	0	0	0	0	0	0	0	0	0	0	0
% Reduction of Turbidities in Individual Chambers												
1	84	62	-	-	82	56	74	67	67	80	77	77
2	81	76	-	-	82	60	83	71	42	76	81	77
3	89	75	-	-	87	69	85	78	82	84	80	88
4	85	76	-	-	62	57	77	67	71	80	83	81
5	84	75	-	-	84	54	77	75	71	80	86	78
6	84	73	-	-	84	71	77	67	71	80	81	73
7	85	78	-	-	87	71	82	75	75	88	88	84

APPENDIX A

Table 2: RECYCLE TESTS

Test No.	7		8		9		10	
Saturation Pressure, psig	30	30	50	30	50	30	30	30
Recycle Rate, GPM	500	800	800	800	500	500	800	500
Feed Turbidity, JTU	44	44	52	52	46	42	46	62
Product Turbidity	11	8.5	8	9.5	13	12	12	27
% Reduction	75	81	85	82	72	71	74	56
Feed Oil, mg/l	42	95	66	66	47	41	47	57
Prod. Oil, mg/l	15	9	8	12	15	14	18	24
% Reduction	64	91	88	82	68	66	62	58
Feed Solids, mg/l	17	16	22	22	17	12	7	16
Prod. Solids, mg/l	11	11	-	12	11	11	10	12
% Reduction	35	31	-	35	35	8	Neg.	25
Air/(Oil & Solids)	0.09	0.08	0.15	0.09	0.12	0.09	0.16	0.08
Water Flow, MGD	27	27	30	30	29	29	25	25
Alum, mg/l	44	44	40	40	41	41	39	39
Polymer, mg/l	0.27	0.27	0.20	0.20	0.21	0.21	0.24	0.24
% Recycle	18	30	27	27	17	17	32	20
pH	7.1	7.1	7.1	7.1	7.3	7.2	7.2	7.0
Temperature, °F	81	81	81	81	82	82	74	74
Sulfonates, mg/l	0	0	0	0	0	1.4	0	1.0
% Reduction of Turbidities in Individual Chambers								
1	82	84	96	85	80	82	76	61
2	66	75	82	77	59	69	62	53
3	70	79	85	73	76	64	74	51
4	81	84	86	85	56	61	74	55
5	77	82	86	83	77	77	72	61
6	67	72	85	71	74	62	74	55
7	80	82	85	79	78	76	74	60

APPENDIX A

Table 3: CHEMICAL DOSAGE TESTS

Test No.	11a	11b	11c	12	13a	13b	14a	14b	14c	14d	15a	15b
Polyelectrolyte, mg/l	0.20	0.20	2.50	0.19	0.22	0.41	0.22	0.0	0.0	0.41	0.20	0.20
Alum, mg/l	35	80	80	70	41	70	31	32	75	32	43	200
MGPD	30	30	30	29	29	29	27	26	27	26	28	27
Recycle, %	23	23	23	28	28	28	30	31	30	31	29	30
Air Sat. Press, psig	50	50	50	50	50	50	50	50	50	50	50	50
Turbidity, JTU												
Feed	38	38	38	48	40	38	39	39	34	42	44	39
Product	16	23	5.5	12	12	4	8	9	6	7	8	11
% Reduction	58	39	85	75	70	89	79	77	82	83	82	72
I.R. Oil, mg/l												
Feed	24	49	49	56	45	67	26	42	34	41	25	25
Product	19	36	11	18	17	11	7	14	11	-	12	12
% Reduction	20	28	77	68	62	83	73	66	67	-	52	52
Sus. Solids, mg/l												
Feed	25	14	14	27	18	34	25	22	25	14	21	23
Product	17	28	7	14	10	9	6	5	11	4	11	22
% Reduction	32	Neg.	50	48	45	73	76	77	56	71	48	4
pH	7.1	7.1	7.2	7.1	7.5	7.5	7.5	7.4	7.4	7.3	7.1	6.6
Sulfonates, mg/l	-	-	-	0	0	0	0	0	0	0	0	0
% Reduction of Turbidity												
1	-	-	-	81	70	88	72	77	82	86	86	77
2	-	-	-	-	81	89	74	62	79	81	78	78
3	-	-	-	85	79	92	82	80	86	87	77	64
4	-	-	-	81	90	91	82	80	76	83	81	67
5	-	-	-	83	85	92	85	80	82	86	73	56
6	-	-	-	83	87	87	82	80	85	82	73	64
7	-	-	-	81	82	84	77	80	82	87	82	64

APPENDIX A

Table 4: CHEMICAL DOSAGE TESTS

Test No.	16a	16b	17a	17b	18a	18b	19a	19b
Polyelectrolyte, mg/l	0.21	0	0.21	0	0	0	0	0.21
Alum, mg/l	41	41	41	41	41	25	25	25
MGPD	29	29	29	29	29	29	28	28
% Recycle	28	28	28	28	28	28	29	29
Sat. Press. psig	50	50	50	50	50	50	50	50
Turbidity, JTU								
Feed	34	37	35	35	39	42	50	43
Effluent	7	8	5	6	8	9	15	12
% Reduction	79	78	86	83	79	79	70	72
I.R. Oil, mg/l								
Feed	44	52	60	36	62	67	71	58
Effluent	10	14	11	14	14	12	23	17
% Reduction	77	73	82	61	77	81	67	71
Sus. Solids, mg/l								
Feed	20	22	38	14	35	24	19	20
Effluent	9	8	8	6	10	10	13	11
% Reduction	55	66	80	61	73	58	32	45
pH	7.4	7.3	7.3	7.2	7.3	7.4	7.5	-
Sulfonates, mg/l	2	2	2	2	3	3	14	13
Temp. °F	75	75	73	73	76	76	74	74
% Reduction of Turbidity in Each Chamber								
1	79	-	83	81	79	80	74	74
2	79	-	81	80	77	78	66	70
3	85	-	84	88	81	82	70	72
4	79	-	83	86	77	81	64	67
5	79	-	86	83	77	76	68	65
6	77	-	83	80	77	76	72	63
7	67	-	81	88	79	81	74	77

APPENDIX A

Table 5: TESTS TO COMPARE COMPETITIVE POLYELECTROLYTES

Test No.	20a	20b	20c	21a	21b	21c
Polyelectrolyte*	Product A	Product B	None	Product C	Product A	Product B
Saturation Press, psig	50	50	50	50	50	50
Recycle Rate--GPM/Chamb.	800	800	800	800	800	800
Feed Turbidity	61	61	61	380	380	380
Effluent Turbidity	8	11	9	24	25	26
% Reduction	87	82	85	94	93	93
Feed--I.R. Oil, mg/l	74	74	74	147	147	147
Effluent Oil, mg/l	22	19	18	19	23	25
% Reduction	70	74	76	87	84	83
Feed Solids, mg/l	13	13	13	23	23	23
Effluent Solids, mg/l	15	10	9	4	4	3
% Reduction	Neg.	23	30	83	83	87
Water Flow, MGD	29	29	29	25	25	25
% Recycle	28	28	28	32	32	32
Alum, mg/l	33	33	33	38	38	38
Polymer, mg/l	0.21	0.21	0.0	0.31	0.36	0.34
pH	7.6	7.6	7.6	7.3	7.3	7.3
Temperature, °F						
Sulfonates, mg/l	0	0	0	3	3	3

*Polyelectrolyte	Product
A	Percol 155
B	WT 2700
C	Atlasep 1A1

APPENDIX A

Table 6: EFFECT OF SKIMMER SPEED ON SCUM QUALITY

Date	Chamber	Speed Ft/Min	SOXHLET, Analysis, %		
			Oil	Solids	Water
12/13/71	2	2.75	6.0	2.2	91.8
	2	5.0	4.6	1.7	93.7
	3	1.4	4.9	2.1	93.0
	3	2.75	4.4	1.7	93.9
	3	5.0	3.5	1.3	95.2
12/16/71	2	2.5	4.4	2.0	93.6
	2	5.0	3.9	1.6	94.5
	3	1.8	4.5	1.8	93.7
	3	3.5	4.0	1.6	94.4
02/02/72	3	1.2	5.8	2.9	91.3
	3	3.0	5.8	2.7	91.5
	3	6.7	5.2	2.2	92.6
	2	3.3	6.8	2.3	90.9
02/25/72	3	1.1	8.5	3.0	88.5
	3	3.3	6.6	2.5	90.9
	2	3.0	8.3	2.9	88.8
03/07/72	3	1.3	7.3	2.4	90.3
	3	6.0	5.3	2.1	92.6
	7	3.0	6.4	2.0	91.6
	7	6.0	5.5	1.9	92.6

APPENDIX A

Table 7: ALUM USAGE AND SCUM PRODUCTION

Month	Alum Usage, Lbs/Day	Scum Production, Gals./Day
January, 1971	8,800	42,000
February	8,200	35,000
March	8,500	33,000
April	8,300	34,000
May	7,500	35,000
June	8,900	32,000
July	11,300	39,000
August	10,500	35,000
September	11,700	42,000
October	11,900	42,000
November	12,900	57,000
December	15,000	62,000
January, 1972	14,300	61,000

APPENDIX A

Table 8: PILOT PLANT TESTS: EFFECT OF OVERFLOW RATE AND REYNOLDS NUMBER ON TURBIDITY REMOVAL

Date	Flotation Area	Flow Rate	Overflow Rate	Reynolds Number	Turbidity In	Turbidity Out	% Reduction
9-15-71	7.5	25	3.3	5600	250	20	92
9-15-71	10.0	25	2.5	5600	200	12	94
9-15-71	20.0	25	1.2	5600	180	8	95
9-15-71	5.0	25	5.0	5600	150	18	88
9-16-71	10.0	19	1.9	4100	42	6	86
9-16-71	20.0	19	0.9	4100	41	4	90
9-16-71	7.5	19	2.5	4100	37	5	87
9-16-71	5.0	19	3.8	4100	38	8	79
9-21-71	20.0	41	2.0	8750	33	3	91
9-21-71	7.5	41	5.4	8750	33	5	85
9-21-71	10.0	41	4.0	8750	38	5	87
9-21-71	5.0	41	8.1	8750	36	11	69
9-22-71	5.0	47	9.4	10200	29	10	66
9-22-71	20.0	47	2.3	10200	29	4	86
9-22-71	10.0	47	4.7	10200	30	4	87
9-22-71	7.5	47	6.2	10200	30	6	80
9-24-71	7.5	32.5	4.3	7200	32	6	81
9-24-71	20.0	32.5	1.6	7200	32	2.5	92
9-24-71	10.0	32.5	13.2	7200	30	3	90
9-24-71	5.0	32.5	6.5	7200	31	8	74
10-11-71	20	47	2.3	10200	51	2.5	95
10-11-71	10	47	4.7	10200	48	5	90
10-11-71	7.5	47	6.2	10200	51	9	82
10-11-71	7.5	19	2.5	4100	53	3	94
10-11-71	5.0	19	3.8	4100	51	5	90

APPENDIX A

Table 9: PILOT PLANT TESTS SUSPENDED SOLIDS DATA

Date	Flotation Area	Flow Rate	Overflow Rate	Reynolds Number	Suspended Solids (mg/l) In	Suspended Solids (mg/l) Out	% Reduction
10-11-71	20	47	2.3	10200	30	6	80
10-11-71	10	47	4.7	10200	29	8	72
10-11-71	7.5	47	6.2	10200	28	10	64
10-11-71	7.5	19	2.5	4100	29	5	83
10-11-71	5.0	19	3.8	4100	29	8	72

I.R. OIL DATA

Date	Flotation Area	Flow Rate	Overflow Rate	Reynolds Number	I.R. Oil (mg/l) In	I.R. Oil (mg/l) Out	% Reduction
10-11-71	20	47	2.3	10200	128	10	92
10-11-71	10	47	4.7	10200	127	14	89
10-11-71	7.5	47	6.2	10200	110	21	81
10-11-71	7.5	19	2.5	4100	109	9	92
10-11-71	5.0	19	3.8	4100	116	12	90

APPENDIX A

Table 10: EFFECT OF REDUCING THROUGHPUT ON UNIT PERFORMANCE (1)

Date	Jackson Turbidity Units				
	Test Chamber at 80% Recycle			Test Chamber at 30% Recycle	
	Feed	Test Chamber	Unit	Test Chamber	Unit
1/11	60	5.4	16	-	-
1/18	60	9.5	20	20	20
1/18	60	12.0	20	20	20
1/20	48	6.0	9.0	-	-
1/20	55	5.5	11	-	-
2/3	120	12	28	-	-
2/10	80	8	18	-	-
2/11	110	20	40	-	-
2/28	66	7.5	12	-	-
2/28	63	7.5	12	11	12
2/28	68	7.8	13	10	13
2/28	65	6.4	12	-	-
Avg.	71	9	18	15	16
% Reduction		87	74	76	74

(1) Test Chamber--1,000 GPM Plus Recycle at 50 PSIG
Other Six Chambers--3,000 GPM Plus 25% Recycle at 50 PSIG

APPENDIX A

Table 11: TURBIDITY DATA OF SAMPLES FROM REYNOLDS NUMBER TEST CHAMBER

Date	Sample Depth, Ft	Turbidity, JTU	
		Test Chamber	AFU
2/16/72	1	28	34
	4	14	32
	6	9	15
2/17/72	1	9	23
	4	12	17
	6	12	11
2/17/72	1	27	22
	4	9	9
	6	Silt	7.5
3/6/72	3	6.6	7.5
	4	6.0	7.3
	5	6.3	6.4

APPENDIX A

Table 12: PILOT PLANT DATA ON EFFECT OF SULFONATE ADDITION

Date	Sulfonates (mg/l)	Turbidity (JTU)		
		Inlet	Outlet	% Removal
2-18-72	0	47	9	81
	5.2	48	10	79
	10.4	50	10	80
	26	58	59	0
2-25-72	0	51	15	71
	10.2	55	13	76
	19	47	50	0
	25	59	56	0
3-1-72	0	23	7.5	67
	10	27	8	70
	18	21	17	19
	26	26	27	0

APPENDIX B

CONTINUOUS SAMPLERS

DESCRIPTION OF CONTINUOUS SAMPLERS

A 20-gpm sump pump is located in outlet channel and takes suction about two feet below the surface through 1-1/4-inch pipe and supplies a continuous large volume stream to the sampler. At the sampler station, a perstaltic pump conveys a continuous stream through a minimum length 1/4-inch rubber tubing into the 1-gallon glass sample container. The flow rate is adjusted to deliver a volume slightly less than the container volume in the predetermined sample period, usually 24 hours.

Sample lines are flushed daily to dislodge slime growths. The sample line leading to the container intended for I.R. oil analysis is flushed with a measured volume of spectrographic grade carbon tetrachloride to recover any oil that may be adhering to the tubing. Samples intended for BOD analysis are refrigerated.

APPENDIX C

Table 1: WATER QUALITY DATA FEBRUARY, 1971 - PROCESS WATER API SEPARATOR EFFLUENT

DATE	FLOW G/D (M)	OIL I.R. mg/1	OIL APHA mg/1	NH3-N mg/1	PHENOL mg/1	BOD mg/1	COD mg/1	TOD mg/1	pH	TON (M)	TSS mg/1	VSS mg/1	PO4 mg/1
1	31	-	-	-	-	-	-	-	-	-	-	-	-
2	31	-	-	-	-	-	-	-	-	-	-	-	-
3	31	-	-	-	-	-	-	-	-	-	-	-	-
4	31	-	-	-	-	-	-	-	-	-	-	-	-
5	31	205.	-	4.50	1.510	93.9	-	260.	8.3	25.00	34.	-	0.00
6	30	205.	-	4.50	1.510	93.9	-	260.	8.3	25.00	34.	-	0.00
7	30	205.	-	4.50	1.510	93.9	-	260.	8.3	25.00	34.	-	0.00
8	30	111.	-	4.60	2.940	47.0	-	228.	7.5	60.00	16.	10.	0.06
9	30	111.	-	4.60	2.940	47.0	-	228.	7.5	60.00	16.	10.	0.06
10	30	218.	-	5.30	1.730	144.4	-	410.	7.9	90.00	52.	-	0.88
11	30	218.	-	5.30	1.730	144.4	-	410.	7.9	90.00	52.	-	0.88
12	30	157.	-	4.00	2.940	120.0	-	524.	7.4	70.00	70.	-	0.32
13	30	157.	-	4.00	2.940	120.0	-	524.	7.4	70.00	70.	-	0.32
14	30	187.	-	4.20	0.130	160.9	-	185.	8.0	90.00	49.	-	0.32
15	30	187.	-	4.20	0.130	160.9	-	185.	8.0	90.00	49.	-	0.32
16	29	101.	-	4.20	0.900	31.1	-	355.	7.7	20.00	92.	52.	0.56
17	29	101.	-	4.20	0.900	31.1	-	355.	7.7	20.00	92.	52.	0.56
18	29	319.	-	4.00	0.500	78.8	-	320.	7.5	-	56.	-	0.56
19	29	319.	-	4.00	0.500	78.8	-	320.	7.5	-	56.	-	0.56
20	29	155.	-	3.60	0.800	103.3	-	420.	7.7	-	76.	37.	0.32
21	29	155.	-	3.60	0.800	103.3	-	420.	7.7	-	76.	37.	0.32
22	29	78.	-	4.90	0.530	112.2	-	-	8.3	-	35.	19.	0.76
23	29	78.	-	4.90	0.530	112.2	-	-	8.3	-	35.	19.	0.76
24	29	127.	-	4.80	1.030	120.0	-	-	8.2	-	75.	37.	0.66
25	29	127.	-	4.80	1.030	120.0	-	-	8.2	-	75.	37.	0.66
26	29	157.	-	3.40	0.340	-	-	-	7.4	-	70.	-	0.28
27	29	157.	-	3.40	0.340	-	-	-	7.4	-	70.	-	0.28
28	29	-	-	3.20	0.490	-	-	-	7.4	-	51.	-	0.16
AVERAGE	30	166.7		4.27	1.195	100.8		333.	7.8	56.53	55.6	31.0	0.40

APPENDIX C

Table 2: WATER QUALITY DATA FEBRUARY, 1971 - PROCESS WATER BIOPOND EFFLUENT

DATE	FLOW G/D (MM)	OIL		NH$_3$-N mg/1	PHENOL mg/1	BOD mg/1	COD mg/1	TOD mg/1	pH	TON mg/1	TSS mg/1	VSS mg/1	PO$_4$ mg/1	TURB. mg/1
		I.R. mg/1	APHA mg/1											
1	31	-	-	-	-	-	-	-	-	-	-	-	-	60.
2	31	-	-	-	-	-	-	-	-	-	-	-	-	54.
3	31	-	-	4.90	0.950	-	-	660.	7.1	-	-	-	-	77.
4	31	92.	36.4	4.20	0.270	91.7	154.	280.	7.5	80.00	37.	-	0.12	92.
5	31	79.	20.3	3.90	0.380	41.7	102.	85.	7.5	60.00	25.	-	0.06	100.
6	30	39.	8.7	4.00	1.280	36.1	41.	140.	7.8	-	10.	-	0.24	54.
7	30	39.	8.7	4.10	1.280	36.1	41.	140.	7.8	-	10.	-	0.24	41.
8	30	59.	10.2	3.40	0.530	61.7	60.	190.	7.6	40.00	14.	-	0.36	35.
9	30	56.	27.4	4.60	0.000	71.4	181.	620.	7.3	-	89.	40.	0.06	46.
10	30	54.	17.1	4.50	0.130	56.7	37.	210.	7.5	25.00	19.	-	0.06	76.
11	30	143.	36.4	5.30	0.550	56.7	147.	212.	7.9	-	27.	-	0.58	66.
12	30	90.	20.6	0.29	0.290	50.0	102.	115.	7.8	25.00	38.	-	0.44	78.
13	30	59.	21.2	3.90	0.250	73.4	131.	300.	7.4	-	25.	-	0.38	64.
14	30	26.	4.5	3.00	0.130	18.1	86.	75.	7.3	15.00	12.	-	0.34	48.
15	30	26.	4.5	3.00	0.130	18.1	86.	75.	7.3	15.00	12.	-	0.34	42.
16	29	37.	19.7	3.80	0.270	32.8	118.	190.	7.5	-	19.	11.	0.34	57.
17	29	71.	17.0	4.60	0.250	27.8	127.	200.	7.5	12.00	25.	-	0.02	54.
18	29	123.	62.3	4.20	0.390	110.0	233.	700.	7.4	-	83.	-	0.06	59.
19	29	101.	23.8	4.50	0.380	44.2	35.	160.	7.6	20.00	26.	-	0.14	62.
20	29	57.	36.9	3.90	0.290	48.9	118.	335.	7.6	-	36.	-	0.08	69.
21	29	90.	16.5	3.20	0.130	34.5	106.	160.	7.7	-	13.	-	0.12	45.
22	29	50.	12.9	3.40	0.250	36.7	78.	180.	7.5	-	7.	-	0.22	60.
23	29	72.	50.9	4.90	0.310	54.5	131.	368.	7.6	-	32.	20.	0.16	41.
24	29	64.	17.4	5.20	0.250	43.6	110.	190.	8.0	-	25.	-	0.06	83.
25	29	81.	46.2	4.60	0.230	75.6	102.	-	7.7	-	31.	-	0.10	57.
26	29	66.	9.8	4.20	0.310	-	163.	-	7.6	-	14.	-	0.22	75.
27	29	77.	34.8	3.00	0.230	-	122.	-	7.4	-	18.	-	0.08	96.
28	29	57.	9.3	2.80	0.190	-	94.	-	7.6	-	10.	-	-	53.
AVERAGE	30	68.3	22.9	3.89	0.371	50.9	108.	253.	7.5	32.44	26.2	23.6	0.20	62.2

APPENDIX C

Table 3: WATER QUALITY DATA FEBRUARY, 1971 - PROCESS WATER TERTIARY TREATMENT EFFLUENT

DATE	FLOW G/D (MM)	OIL		NH$_3$-N mg/1	PHENOL mg/1	BOD mg/1	COD mg/1	TOD mg/1	pH	TON (M)	TSS mg/1	VSS mg/1	PO$_4$ mg/1	TURB. JTU	TEMP. °F	ALUM. mg/1	POLY. mg/1	SULF. mg/1
		I.R. mg/1	APHA mg/1															
1	31	6.	3.3	4.50	0.140	19.3	12.	60.	7.2	6.00	9.	-	0.02	7.	71	9	.19	-
2	31	11.	3.2	3.00	0.210	19.1	47.	85.	7.0	-	11.	7.	0.02	7.	70	39	.19	-
3	31	17.	7.6	6.00	0.230	136.8	205.	560.	6.9	-	23.	-	0.06	6.	72	39	.19	-
4	31	21.	6.7	4.00	0.170	55.6	92.	130.	7.3	-	12.	-	0.02	44.	73	39	.35	-
5	31	17.	2.3	3.60	0.190	10.8	28.	50.	7.2	5.00	8.	-	0.02	15.	66	39	.31	-
6	30	16.	2.6	4.20	1.060	13.6	35.	70.	7.6	-	12.	-	0.00	13.	69	40	.20	-
7	30	16.	2.6	4.20	1.060	13.6	35.	70.	7.6	-	12.	-	0.00	9.	-	40	.20	-
8	30	15.	2.4	3.60	0.230	15.0	37.	80.	7.5	12.50	10.	-	0.02	10.	68	40	.24	-
9	30	18.	2.0	4.50	0.340	15.0	47.	100.	7.3	-	11.	9.	0.04	7.	67	40	.20	-
10	30	19.	6.5	5.00	0.270	20.8	45.	243.	7.4	25.00	25.	-	0.02	12.	69	40	.24	-
11	30	37.	12.3	5.20	0.340	30.5	45.	161.	7.7	-	21.	-	0.10	12.	72	40	.26	2.5
12	30	39.	6.6	3.20	0.230	31.4	53.	100.	7.7	9.00	15.	-	0.14	12.	72	40	.24	0.9
13	30	12.	10.3	3.90	0.170	61.4	90.	200.	7.7	-	12.	-	0.20	12.	62	40	.24	0.9
14	30	9.	2.4	4.20	0.150	13.3	14.	60.	7.2	7.00	9.	-	0.20	6.	70	40	.20	0.9
15	30	9.	2.4	4.20	0.150	13.3	14.	60.	7.2	7.00	9.	-	0.20	5.	-	40	.20	-
16	29	11.	2.4	3.60	0.140	14.9	18.	65.	7.4	-	8.	5.	0.01	7.	73	41	.21	1.1
17	29	18.	9.7	4.80	0.270	19.9	62.	200.	7.4	10.00	29.	-	0.00	8.	72	24	.21	1.8
18	29	29.	9.9	4.20	0.210	33.5	75.	130.	7.3	-	29.	-	0.02	7.	74	24	.21	1.1
19	29	22.	3.8	4.50	0.170	20.3	43.	70.	7.5	10.00	9.	-	0.06	8.	73	24	.21	0.6
20	29	18.	8.1	3.40	0.150	23.2	54.	85.	7.5	-	8.	-	0.04	9.	73	33	.21	1.0
21	29	14.	3.5	3.10	0.190	17.7	41.	50.	7.6	-	10.	-	0.00	6.	72	33	.21	1.3
22	29	16.	2.5	3.60	0.190	24.1	43.	90.	7.4	-	12.	-	0.00	9.	68	33	.21	1.1
23	29	25.	9.5	5.00	0.170	43.7	86.	180.	7.5	-	27.	17.	0.04	7.	72	33	.21	3.3
24	29	23.	5.6	5.30	0.210	27.1	-	105.	7.6	-	13.	-	0.14	16.	72	41	.25	9.9
25	29	34.	7.1	4.30	0.390	-	-	190.	7.5	-	21.	-	0.22	10.	73	41	.25	6.3
26	29	17.	4.4	4.20	0.250	-	-	-	7.3	-	6.	-	0.24	12.	73	41	.25	14.5
27	29	17.	6.0	3.10	0.170	-	-	-	7.2	-	8.	-	0.00	13.	70	41	.25	4.8
28	29	12.	5.5	2.70	0.130	-	-	-	7.6	-	7.	-	0.06	7.	70	41	.25	3.0
AVERAGE	30	18.5	5.3	4.11	0.270	28.9	53.	127.	7.4	10.16	13.7	9.5	0.06	10.5	71			

APPENDIX C

Table 4: WATER QUALITY DATA MARCH, 1971 - PROCESS WATER API SEPARATOR EFFLUENT

DATE	FLOW G/D (M)	OIL		NH_3-N mg/l	PHENOL mg/l	BOD mg/l	COD mg/l	TOD mg/l	pH	TON (M)	TSS mg/l	VSS mg/l	PO_4 mg/l
		I.R. mg/l	APHA mg/l										
1	29	65.		3.20	0.490	21.1	****	260.	7.7	90.00	51.	****	0.16
2	29	122.		0.30	1.190	71.1	****	300.	7.7	******	26.	****	0.32
3	29	122.		0.30	1.190	71.1	****	300.	7.7	******	26.	****	0.32
4	29	39.		0.14	0.120	77.2	****	105.	7.9	80.00	7.	****	0.54
5	29	39.		0.14	0.120	77.2	****	105.	7.9	80.00	7.	****	0.54
6	29	72.		4.64	0.850	110.0	****	130.	8.0	20.00	8.	****	0.04
7	29	72.		4.64	0.850	110.0	****	130.	8.0	20.00	8.	****	0.04
8	29	****		3.00	0.310	68.9	40.	170.	7.9	25.00	34.	17.	0.20
9	29	****		3.00	0.310	68.9	40.	170.	7.9	25.00	34.	17.	0.20
10	29	421.		3.16	1.640	152.2	****	690.	7.8	90.00	93.	****	0.36
11	29	421.		3.16	1.640	152.2	****	690.	7.8	90.00	93.	****	0.32
12	27	343.		3.76	1.120	267.7	****	420.	7.5	50.00	68.	****	0.36
13	27	343.		3.76	1.120	267.7	****	420.	7.5	50.00	68.	****	0.36
14	32	351.		3.44	4.860	177.2	238.	1170.	8.1	60.00	92.	48.	0.44
15	29	351.		3.44	4.860	177.2	238.	1170.	8.1	60.00	92.	48.	0.44
16	29	132.		3.88	0.680	136.1	****	446.	7.7	80.00	54.	****	0.64
17	26	132.		3.88	0.680	136.1	****	446.	7.7	80.00	54.	****	0.64
18	25	77.		4.40	0.390	46.7	****	195.	7.5	60.00	25.	****	0.36
19	24	77.		4.40	0.390	46.7	****	195.	7.5	60.00	25.	****	0.36
20	26	124.		4.80	2.060	60.5	****	355.	8.0	40.00	40.	****	0.40
21	27	124.		4.80	2.060	60.5	****	355.	8.0	40.00	40.	****	0.40
22	28	264.		5.04	3.280	134.4	447.	710.	7.9	125.00	65.	28.	1.00
23	29	264.		5.04	3.280	134.4	447.	710.	7.9	125.00	65.	28.	1.00
24	28	275.		2.26	2.260	316.0	****	750.	7.4	50.00	95.	****	0.68
25	26	275.		2.26	2.260	316.0	****	750.	7.4	50.00	95.	****	0.68
26	28	124.		3.36	0.250	133.3	****	350.	7.6	30.00	41.	****	0.38
27	27	124.		3.36	0.250	133.3	****	350.	7.6	30.00	41.	****	0.38
28	27	51.		3.64	0.340	66.6	50.	230.	7.6	40.00	19.	****	0.24
29	28	51.		3.64	0.340	66.6	50.	230.	7.6	40.00	19.	****	0.24
30	28	36.		2.92	0.190	58.3	****	120.	7.6	4.00	16.	****	0.22
31	28	36.		2.92	0.190	58.3	****	120.	7.6	4.00	16.	****	0.22
AVERAGE		169.8		3.24	1.276	121.7	328.	404.	7.7	55.10	45.7	31.0	0.40

APPENDIX C

Table 5: WATER QUALITY DATA MARCH, 1971 - PROCESS WATER BIOPOND EFFLUENT

DATE	FLOW G/D (MM)	OIL		NH$_3$-N mg/1	PHENOL mg/1	BOD mg/1	COD mg/1	TOD mg/1	pH	TON (M)	TSS mg/1	VSS mg/1	PO4 mg/1	TURB. JTU
		I.R. mg/1	APHA mg/1											
1	29	40.	8.1	3.80	0.230	16.1	32.	78.	7.7	*****	12.	****	0.32	38.
2	29	37.	6.3	1.70	0.250	9.5	****	68.	7.7	15.00	6.	4.	0.56	37.
3	29	71.	12.3	0.40	0.210	12.0	****	68.	7.7	*****	7.	****	0.30	44.
4	29	57.	70.8	0.30	0.310	39.7	****	480.	7.8	10.00	64.	****	0.44	37.
5	29	39.	7.4	0.12	0.250	37.2	****	90.	8.1	*****	15.	****	0.44	39.
6	29	16.	55.3	4.52	0.210	37.2	****	198.	7.8	50.00	9.	****	0.36	40.
7	29	38.	5.3	4.04	0.170	35.0	****	145.	7.7	*****	12.	****	0.46	51.
8	29	****	12.1	2.60	0.210	32.2	170.	140.	7.6	25.00	14.	****	0.30	42.
9	29	33.	7.2	3.08	0.210	31.1	****	65.	7.6	*****	18.	18.	0.40	43.
10	29	41.	8.1	3.00	0.270	36.1	****	50.	7.6	*****	15.	****	0.44	69.
11	29	54.	25.1	2.52	0.140	53.9	****	55.	7.6	30.00	12.	****	0.40	66.
12	27	49.	10.4	2.76	0.290	45.8	****	170.	7.6	*****	16.	****	0.40	47.
13	27	63.	27.3	3.76	0.190	48.6	****	85.	7.5	25.00	12.	****	0.34	49.
14	32	40.	9.5	3.36	0.190	48.1	****	100.	7.8	*****	11.	****	0.42	46.
15	29	51.	10.8	3.00	0.270	51.9	38.	75.	7.7	18.00	13.	****	0.36	57.
16	29	36.	7.7	3.24	0.310	45.0	****	115.	7.8	*****	15.	8.	0.36	56.
17	26	44.	8.7	3.64	0.210	56.1	****	140.	8.7	13.00	16.	****	0.30	58.
18	25	68.	26.5	3.64	0.360	65.0	****	390.	7.6	*****	35.	****	0.46	48.
19	24	67.	15.6	3.64	0.230	28.9	****	145.	7.6	25.00	25.	****	0.38	62.
20	26	52.	20.1	3.88	0.250	65.9	****	260.	7.6	*****	27.	****	0.22	49.
21	27	27.	6.4	4.16	0.130	17.0	****	90.	7.5	10.00	16.	****	0.30	37.
22	28	28.	6.0	4.16	0.230	26.4	67.	165.	7.5	*****	13.	****	0.30	35.
23	29	79.	23.5	3.96	0.250	35.6	****	310.	7.6	15.00	31.	20.	0.38	43.
24	28	87.	9.4	4.64	0.210	24.5	****	200.	7.7	*****	12.	****	0.66	83.
25	26	60.	15.9	4.80	0.190	****	****	345.	7.5	30.00	25.	****	0.66	97.
26	28	40.	9.4	5.04	0.190	****	****	145.	7.6	*****	17.	****	0.58	84.
27	27	50.	15.5	3.64	0.150	63.4	****	355.	7.5	13.00	31.	****	0.38	70.
28	27	35.	15.2	3.36	0.290	51.4	****	510.	7.5	*****	50.	****	0.36	51.
29	28	39.	****	3.44	0.170	25.0	72.	170.	7.6	6.00	14.	****	0.32	43.
30	28	53.	10.4	3.56	0.210	25.0	****	150.	7.5	*****	14.	14.	0.38	48.
31	28	30.	8.0	3.08	0.150	27.0	****	104.	7.6	5.00	16.	****	0.34	60.
AVERAGE		47.4	15.8	3.25	0.223	37.6	75.	176.	7.6	19.33	19.1	12.8	0.39	52.5

APPENDIX C

Table 6: WATER QUALITY DATA MARCH, 1971 - PROCESS WATER TERTIARY TREATMENT EFFLUENT

DATE	FLOW G/D (M)	OIL		NH_3-N mg/1	PHENOL mg/1	BOD mg/1	COD mg/1	TOD mg/1	pH	TON (M)	TSS mg/1	VSS mg/1	PO_4 mg/1	TURB. JTU	TEMP. °F	ALUM. mg/1	POLY. mg/1	SULF. mg/1
		I.R. mg/1	APHA mg/1															
1	29	13.	2.9	3.60	0.170	2.7	53.	49.	7.3	*****	4.	***	0.08	5.	73	33	.21	.1
2	29	15.	3.5	1.70	0.170	3.2	***	49.	7.5	4.00	8.	4.	0.18	6.	72	33	.21	.1
3	29	13.	2.6	0.30	0.230	4.2	***	40.	7.6	*****	6.	***	0.04	7.	71	33	.21	.1
4	29	19.	4.1	0.20	0.170	13.7	***	55.	7.7	5.00	9.	***	0.12	8.	72	37	.24	.1
5	29	11.	2.1	0.12	0.140	29.1	***	55.	7.8	*****	8.	***	0.02	8.	72	41	.22	.1
6	29	14.	2.2	4.52	0.120	24.5	***	60.	7.8	4.00	6.	***	0.16	8.	73	41	.21	.1
7	29	***	***	****	*****	****	***	****	7.5	*****	***	***	****	16.	70	41	.22	2.0
8	29	18.	4.7	2.44	0.170	33.4	***	50.	7.5	3.00	8.	***	0.08	6.	69	41	.21	.1
9	29	***	2.9	****	*****	****	***	****	***	*****	***	***	****	6.	73	41	.21	.1
10	29	12.	2.8	2.92	0.210	22.9	48.	67.	7.5	*****	10.	***	0.08	6.	73	41	.21	1.3
11	29	15.	3.6	2.28	0.150	21.3	***	67.	7.5	3.00	7.	***	0.04	7.	75	41	.21	.1
12	27	16.	6.0	3.16	0.250	26.7	***	80.	7.5	*****	29.	***	0.08	6.	73	44	.22	.1
13	27	17.	4.2	3.56	0.230	28.5	***	50.	7.4	5.00	8.	***	0.10	9.	74	44	0	.1
14	32	19.	4.2	3.36	0.190	22.7	***	40.	7.7	*****	12.	***	0.16	8.	76	37	0	.1
15	29	22.	7.8	2.68	0.290	20.8	51.	75.	7.6	6.00	7.	***	0.10	8.	76	26	0	3.1
16	29	22.	4.8	3.16	0.250	20.4	***	95.	7.6	*****	18.	5.	0.10	14.	74	21	.21	8.6
17	26	18.	4.4	3.64	0.230	21.6	***	100.	7.9	3.00	30.	***	0.14	14.	75	29	.28	8.6
18	25	20.	5.8	3.64	0.170	9.1	***	130.	7.5	*****	9.	***	0.06	22.	75	58	.34	9.4
19	24	21.	2.3	3.88	0.170	21.0	***	85.	7.4	2.50	9.	***	0.08	12.	76	60	.35	9.4
20	26	24.	4.5	3.64	0.140	10.2	***	85.	7.4	*****	7.	***	0.14	9.	73	46	.28	3.0
21	27	34.	6.5	4.28	0.190	9.6	***	110.	7.5	2.50	24.	***	0.06	7.	75	44	.22	.1
22	28	25.	7.4	4.40	0.190	19.9	27.	170.	7.3	*****	45.	***	0.10	7.	76	43	0	.3
23	29	41.	***	3.88	0.250	18.6	***	420.	7.4	10.00	30.	13.	0.18	11.	73	41	.21	6.3
24	28	22.	3.6	3.96	0.160	22.2	***	85.	7.6	*****	6.	***	0.18	32.	73	43	.30	10.2
25	26	20.	3.6	5.04	0.230	****	***	85.	7.3	6.00	12.	***	0.10	18.	73	46	.32	9.7
26	28	16.	2.8	4.92	0.150	39.5	***	117.	7.5	*****	10.	***	0.06	12.	73	43	.30	3.9
27	27	15.	2.9	3.36	0.190	26.7	***	110.	7.4	4.00	17.	***	0.14	11.	75	44	.36	2.0
28	27	14.	2.2	3.64	0.230	27.2	***	60.	7.3	*****	14.	***	0.02	8.	76	44	.27	2.5
29	28	9.	9.8	3.64	0.140	12.2	46.	100.	7.4	2.00	8.	***	0.10	8.	74	43	.26	0
30	28	9.	2.6	3.64	0.140	14.1	***	85.	7.3	*****	5.	5.	0.12	7.	75	39	.30	0
31	28	9.	2.0	3.24	0.130	18.1	***	75.	7.5	3.00	11.	***	0.22	8.	75	43	.30	0
AVERAGE		18.0	4.0	3.19	0.187	19.4	45.	91.	7.5	4.20	13.0	6.7	0.10	10.1				

APPENDIX C

Table 7: WATER QUALITY DATA APRIL, 1971 - PROCESS WATER API SEPARATOR EFFLUENT

DATE	FLOW G/D (M)	OIL I.R. mg/l	OIL APHA mg/l	NH_3-N mg/l	PHENOL mg/l	BOD mg/l	COD mg/l	TOD mg/l	pH	TON (M)	TSS mg/l	VSS mg/l	PO_4 mg/l
1	30	86.		2.84	0.680	99.4	****	225.	7.4	17.00	28.	****	0.36
2	26	86.		2.84	0.680	99.4	****	225.	7.4	17.00	28.	****	0.36
3	22	98.		3.08	3.200	93.3	****	495.	7.7	25.00	32.	****	****
4	25	98.		3.08	3.200	93.3	****	495.	7.7	25.00	32.	****	****
5	24	36.		3.08	0.660	90.5	76.	120.	7.5	40.00	15.	11.	****
6	26	36.		3.08	0.660	90.5	****	120.	7.5	40.00	15.	11.	****
7	26	39.		3.64	0.230	24.4	****	131.	7.5	40.00	21.	****	0.38
8	26	****		3.64	0.230	24.4	****	131.	7.5	40.00	21.	****	0.38
9	25	****		3.64	0.230	24.4	****	131.	7.5	40.00	21.	****	0.38
10	22	89.		3.88	0.680	47.2	****	350.	7.4	90.00	37.	****	0.00
11	23	89.		3.88	0.680	47.2	****	350.	7.4	90.00	37.	****	0.00
12	24	47.		3.36	0.210	42.2	110.	145.	7.5	40.00	23.	9.	0.70
13	22	47.		3.36	0.210	42.2	110.	145.	7.5	40.00	22.	9.	0.70
14	25	102.		2.36	0.950	108.3	****	210.	7.4	50.00	47.	****	0.44
15	25	102.		2.36	0.950	108.3	****	210.	7.4	50.00	47.	****	0.44
16	28	128.		3.24	0.380	100.5	****	370.	7.4	60.00	55.	****	0.32
17	27	128.		3.24	0.380	100.5	****	370.	7.4	60.00	55.	****	0.32
18	27	53.		5.32	5.000	185.5	334.	1160.	8.4	60.00	47.	****	0.50
19	27	53.		5.32	5.000	185.5	334.	1160.	8.4	60.00	47.	****	0.50
20	27	193.		4.52	2.940	143.3	204.	520.	7.5	30.00	60.	23.	0.50
21	27	193.		4.52	2.940	143.3	204.	520.	7.5	30.00	60.	23.	0.50
22	27	80.		3.16	0.680	54.4	****	122.	7.4	30.00	28.	****	0.20
23	28	80.		3.16	0.680	54.4	****	122.	7.4	30.00	28.	****	0.20
24	26	77.		2.60	0.380	50.5	****	265.	7.5	80.00	37.	****	0.32
25	29	77.		2.60	0.380	50.5	****	265.	7.5	80.00	37.	****	0.32
26	29	185.		2.76	1.250	86.1	179.	562.	7.8	50.00	111.	29.	0.54
27	27	185.		2.76	1.250	86.1	179.	562.	***	50.00	111.	29.	0.54
28	28	153.		3.30	0.970	51.7	****	****	7.5	60.00	52.	26.	0.28
29	26	153.		3.30	0.970	51.7	****	340.	7.5	60.00	52.	26.	0.28
30	26	142.		1.28	0.430	58.9	****	360.	7.4	40.00	48.	****	0.16
AVERAGE		101.2		3.30	1.235	81.2	192.	351.	7.5	47.46	41.8	19.6	0.37

APPENDIX C

Table 8: WATER QUALITY DATA APRIL, 1971 - PROCESS WATER BIOPOND EFFLUENT

DATE	FLOW G/D (MM)	OIL		NH$_3$-N mg/l	PHENOL mg/l	BOD mg/l	COD mg/l	TOD mg/l	pH	TON mg/l	TSS mg/l	VSS mg/l	PO$_4$ mg/l	TURB. JTU
		I.R. mg/l	APHA mg/l											
1	30	70.	29.7	1.92	0.210	38.9	****	240.	7.6	*****	13.	****	0.24	45.
2	26	47.	12.8	2.52	0.230	37.5	****	123.	7.4	5.00	17.	****	0.30	****
3	22	60.	28.0	2.76	0.210	43.9	****	298.	7.6	*****	24.	****	0.36	46.
4	25	33.	7.3	2.52	0.190	36.9	****	151.	7.6	5.00	12.	****	0.56	54.
5	24	30.	7.1	2.68	0.210	38.9	72.	130.	7.7	*****	9.	****	0.56	40.
6	26	31.	7.1	2.84	0.170	38.1	****	150.	7.5	5.00	14.	8.	0.64	54.
7	26	33.	5.6	2.84	0.190	35.0	****	80.	7.8	*****	14.	****	0.58	49.
8	26	30.	10.8	3.24	0.250	20.3	****	120.	7.4	25.00	23.	****	0.60	78.
9	25	39.	10.8	3.24	0.250	20.3	****	120.	7.4	*****	23.	****	0.60	77.
10	22	54.	23.4	4.04	0.250	20.0	****	221.	7.3	*****	23.	****	0.58	61.
11	23	30.	5.7	3.16	0.100	15.3	****	110.	7.5	30.00	10.	****	0.52	49.
12	24	25.	7.0	3.44	0.170	55.5	130.	220.	7.6	*****	16.	****	0.30	43.
13	22	46.	8.4	3.00	0.170	23.4	****	118.	7.6	25.00	12.	7.	0.28	44.
14	25	35.	12.5	3.00	0.230	23.7	****	121.	7.5	*****	23.	****	0.32	31.
15	25	58.	30.0	2.76	0.170	46.1	****	172.	7.4	40.00	28.	****	0.32	32.
16	28	57.	10.0	2.84	0.150	50.9	****	80.	7.6	*****	18.	****	0.28	37.
17	27	56.	17.9	2.92	0.140	46.1	****	120.	7.4	25.00	21.	****	0.24	36.
18	27	33.	9.4	3.00	0.170	35.8	****	90.	7.5	*****	15.	****	0.26	34.
19	27	47.	10.0	3.88	0.190	43.3	77.	170.	7.4	30.00	25.	****	0.40	35.
20	27	51.	15.7	4.64	0.310	43.4	****	185.	7.3	*****	19.	14.	0.34	48.
21	27	77.	38.1	4.52	0.210	54.2	****	220.	***	25.00	34.	****	0.26	51.
22	27	66.	30.5	3.88	0.230	30.6	****	215.	7.5	*****	43.	****	0.32	48.
23	28	51.	12.8	2.84	0.170	23.3	****	48.	7.6	15.00	16.	****	0.36	39.
24	26	65.	25.4	3.08	0.230	42.8	****	270.	7.5	*****	27.	****	0.30	51.
25	29	57.	10.0	3.76	0.210	30.8	****	170.	7.5	25.00	22.	****	0.22	45.
26	29	33.	9.2	1.92	0.150	20.0	108.	105.	7.7	*****	24.	****	0.14	73.
27	27	80.	37.9	2.16	0.210	28.4	****	325.	7.7	40.00	52.	35.	0.28	48.
28	28	64.	37.1	2.20	0.230	38.6	****	192.	7.5	*****	34.	****	0.20	56.
29	26	65.	39.6	3.21	0.230	20.9	****	269.	7.5	50.00	31.	****	0.24	57.
30	26	40.	14.2	1.92	0.250	13.3	****	100.	7.6	*****	17.	****	0.20	63.
AVERAGE		48.7	17.4	3.02	0.202	33.8	96.	164.	7.5	24.64	21.9	16.0	0.35	49.1

APPENDIX C

Table 9: WATER QUALITY DATA APRIL, 1971 - PROCESS WATER TERTIARY TREATMENT EFFLUENT

DATE	FLOW G/D (M)	OIL		NH_3-N mg/1	PHENOL mg/1	BOD mg/1	COD mg/1	TOD mg/1	pH	TON (M)	TSS mg/1	VSS mg/1	PO_4 mg/1	TURB. JTU	TEMP. °F	ALUM. mg/1	POLY. mg/1	SULF. mg/1
		I.R. mg/1	APHA mg/1															
1	30	15.	4.0	2.20	0.130	28.4	****	85.	7.4	*****	15.	****	0.40	7.	75	40	.24	0
2	26	31.	3.4	2.68	0.150	25.9	****	55.	7.7	2.50	11.	****	0.16	***	73	46	.28	0
3	22	17.	4.9	2.52	0.140	32.1	****	112.	7.6	*****	7.	****	0.00	7.	74	54	.33	0
4	25	9.	3.8	2.36	0.190	17.4	****	69.	7.4	3.00	9.	****	0.04	8.	78	48	.29	0
5	24	12.	2.9	2.44	0.140	26.7	11.	59.	7.6	*****	7.	****	0.02	7.	75	50	.30	0
6	26	8.	5.0	2.68	0.210	28.0	****	95.	7.4	5.00	12.	9.	0.06	10.	74	46	.28	0
7	26	13.	2.2	2.68	0.130	25.3	****	70.	8.2	*****	12.	****	0.06	13.	78	60	.37	0
8	26	12.	2.3	3.24	0.140	17.5	****	50.	7.2	10.00	9.	****	0.00	12.	79	46	.25	0
9	25	12.	2.3	3.24	0.140	17.5	****	50.	7.2	*****	9.	****	0.00	9.	-	48	.26	0
10	22	10.	3.0	3.88	0.140	16.3	****	60.	7.3	*****	9.	****	****	8.	70	54	.27	0
11	23	11.	1.7	3.36	0.190	10.7	****	62.	7.3	3.00	8.	****	0.00	7.	79	52	.26	0
12	24	13.	2.1	3.96	0.120	****	100.	170.	7.4	*****	6.	****	0.08	7.	80	55	.35	0
13	22	18.	2.5	2.84	0.140	27.0	****	68.	7.4	4.00	12.	12.	0.00	8.	78	54	.27	0
14	25	20.	3.6	2.28	0.150	15.3	****	60.	7.3	*****	12.	****	0.22	6.	79	29	.24	0
15	25	11.	4.1	2.84	0.150	13.2	****	60.	7.3	2.50	14.	****	0.20	9.	79	39	.24	0
16	28	10.	1.8	2.84	0.110	10.0	****	30.	7.5	*****	9.	****	0.14	7.	80	33	.21	0
17	27	17.	6.8	2.92	0.120	12.0	****	65.	7.3	2.00	26.	****	0.18	8.	79	36	.22	0
18	27	11.	3.6	2.60	0.140	13.6	****	55.	7.4	*****	19.	****	0.12	8.	80	36	.22	0
19	27	12.	4.2	3.96	0.210	17.2	35.	60.	7.3	3.00	15.	****	0.12	7.	80	36	.22	0
20	27	16.	2.6	5.04	0.170	19.1	****	70.	7.4	*****	15.	14.	0.14	12.	81	36	.22	0
21	27	25.	8.2	4.40	0.190	24.9	****	120.	7.3	25.00	25.	****	0.08	19.	79	45	.31	0
22	27	19.	5.9	3.96	0.170	12.4	****	52.	7.4	*****	17.	****	0.12	12.	78	36	.22	0
23	28	15.	3.2	2.92	0.150	15.8	****	49.	7.3	1.50	18.	****	0.12	10.	80	34	.24	0
24	26	17.	9.6	3.08	0.150	25.5	****	120.	7.4	*****	22.	****	0.12	9.	77	37	.23	0
25	29	16.	4.8	3.88	0.150	26.7	****	95.	7.4	2.00	11.	****	0.16	8.	80	33	.21	0
26	29	13.	3.2	2.16	0.120	14.9	****	50.	7.6	*****	9.	****	0.14	12.	79	45	.29	0
27	27	18.	9.6	2.20	0.170	17.7	****	111.	7.6	1.75	26.	11.	0.08	10.	75	44	.27	0
28	28	17.	6.2	2.20	0.170	16.4	****	60.	7.2	*****	15.	****	0.12	8.	79	43	.21	.3
29	26	16.	5.0	3.13	0.190	17.8	****	75.	7.4	2.50	15.	****	0.12	11.	78	46	.23	0
30	26	12.	2.5	1.80	0.190	8.6	****	40.	7.6	*****	9.	****	0.08	10.	78	46	.23	0
AVERAGE		14.8	4.1	3.00	0.155	19.0	48.	72.	7.4	4.83	13.4	11.5	0.10	9.2				

APPENDIX C

Table 10: WATER QUALITY DATA MAY, 1971 - PROCESS WATER API SEPARATOR EFFLUENT

DATE	FLOW G/D (M)	OIL		NH$_3$-N mg/1	PHENOL mg/1	BOD mg/1	COD mg/1	TOD mg/1	pH	TON (M)	TSS mg/1	VSS mg/1	PO$_4$ mg/1
		I.R. mg/1	APHA mg/1										
1	25	142.		1.28	0.430	58.9	****	360.	7.4	40.00	48.	****	0.16
2	25	16.		2.36	3.100	93.9	229.	425.	7.5	50.00	45.	****	****
3	26	16.		2.36	3.100	93.9	229.	425.	7.5	50.00	45.	****	****
4	23	296.		3.52	0.390	100.5	****	590.	7.6	80.00	115.	28.	0.66
5	29	296.		3.52	0.390	100.5	****	590.	7.6	80.00	115.	28.	0.66
6	23	191.		3.08	0.290	137.7	****	415.	7.6	50.00	55.	****	0.56
7	23	191.		3.08	0.290	137.7	****	415.	7.6	50.00	55.	****	0.56
8	25	71.		2.52	0.140	48.9	****	200.	7.7	40.00	31.	****	0.42
9	25	71.		2.52	0.140	48.9	****	200.	7.7	40.00	31.	****	0.42
10	27	207.		2.60	0.530	112.2	254.	504.	7.9	60.00	75.	37.	0.24
11	24	207.		2.60	0.530	112.2	254.	5.	7.9	60.00	75.	37.	0.24
12	24	210.		4.80	0.500	88.9	****	480.	7.3	50.00	48.	****	0.30
13	26	210.		4.80	0.500	88.9	****	480.	7.3	50.00	48.	****	0.30
14	26	110.		4.52	0.150	65.5	****	190.	7.5	70.00	31.	****	0.12
15	24	110.		4.52	0.150	65.5	****	190.	7.5	70.00	31.	****	0.12
16	24	22.		2.68	0.170	10.0	****	55.	7.7	20.00	10.	****	0.18
17	26	22.		2.68	0.170	10.0	36.	55.	7.7	20.00	10.	****	0.18
18	26	287.		2.92	0.450	91.1	36.	440.	7.5	40.00	54.	32.	0.22
19	21	287.		2.92	0.450	91.1	****	440.	7.5	40.00	54.	32.	0.22
20	21	72.		1.92	1.090	398.2	****	672.	7.5	50.00	31.	****	0.06
21	22	72.		1.92	1.090	398.2	****	672.	7.5	50.00	31.	****	0.06
22	22	95.		2.16	0.530	51.1	****	135.	7.4	50.00	20.	****	0.04
23	21	95.		2.16	0.530	51.1	****	135.	7.4	50.00	20.	****	0.04
24	22	33.		1.04	0.880	38.3	91.	110.	7.4	40.00	15.	10.	0.06
25	22	33.		1.04	0.880	38.3	91.	110.	7.4	40.00	15.	10.	0.06
26	22	191.		3.36	1.250	111.6	****	240.	7.4	50.00	28.	****	0.24
27	23	190.		3.36	1.250	111.6	****	240.	7.4	50.00	28.	****	0.24
28	22	100.		1.28	0.250	72.8	****	190.	7.7	60.00	34.	****	0.28
29	22	100.		1.28	0.250	72.8	****	190.	7.7	60.00	34.	****	0.28
30	23	301.		1.24	1.510	91.6	****	295.	7.8	90.00	22.	****	0.08
31	28	301.		1.24	1.510	91.6	****	295.	7.8	90.00	22.	****	0.08
AVERAGE		146.6		2.62	0.738	99.4	152.	314.	7.5	52.90	41.1	26.7	0.24

APPENDIX C

Table 11: WATER QUALITY DATA MAY, 1971 - PROCESS WATER BIOPOND EFFLUENT

DATE	FLOW G/D (MM)	OIL		NH$_3$-N mg/1	PHENOL mg/1	BOD mg/1	COD mg/1	TOD mg/1	pH	TON (M)	TSS mg/1	VSS mg/1	PO$_4$ mg/1	TURB. JTU
		I.R. mg/1	APHA mg/1											
1	25	67.	24.3	1.16	0.170	49.7	****	220.	7.5	20.00	31.	****	0.31	41.
2	25	37.	11.9	0.88	0.230	24.5	****	90.	7.7	*****	11.	****	0.30	46.
3	26	39.	6.6	1.44	0.210	13.3	125.	130.	7.6	10.00	20.	****	0.36	40.
4	23	69.	38.9	1.84	0.310	45.3	****	320.	7.7	*****	41.	21.	0.42	43.
5	29	57.	21.4	3.12	0.250	60.6	****	222.	7.6	25.00	44.	****	0.40	50.
6	23	66.	26.1	2.08	0.210	28.9	****	192.	7.7	*****	19.	****	0.68	75.
7	23	58.	17.1	3.64	0.290	112.3	****	270.	7.7	40.00	28.	****	0.68	73.
8	25	57.	26.8	3.76	0.170	55.9	****	190.	7.5	*****	24.	****	0.06	56.
9	25	19.	10.8	2.20	0.120	18.1	****	75.	7.7	25.00	12.	****	0.24	44.
10	27	21.	6.0	1.40	0.150	16.4	65.	85.	7.8	*****	11.	****	0.20	39.
11	24	119.	47.8	1.44	0.190	45.0	****	620.	7.8	30.00	83.	35.	0.44	48.
12	24	80.	40.1	3.16	0.210	29.2	****	220.	7.8	*****	35.	****	0.44	46.
13	26	86.	46.9	4.64	0.210	44.2	****	285.	7.4	25.00	38.	****	0.42	59.
14	26	73.	32.9	4.40	0.230	27.2	****	130.	7.4	*****	24.	****	0.36	63.
15	24	63.	35.4	4.52	0.140	20.9	****	180.	7.5	25.00	27.	****	0.34	58.
16	24	21.	7.1	3.56	0.150	15.9	****	75.	7.7	*****	4.	****	0.32	46.
17	26	27.	8.6	2.00	0.140	10.0	65.	65.	7.7	17.50	9.	****	0.38	37.
18	26	145.	78.6	4.80	0.190	33.6	****	670.	7.7	*****	67.	18.	0.44	88.
19	21	68.	26.1	2.20	0.170	19.8	****	120.	7.6	30.00	26.	****	0.28	88.
20	21	70.	14.3	2.08	0.190	27.2	****	215.	7.5	*****	29.	****	0.56	38.
21	22	22.	8.3	1.04	0.150	17.7	****	73.	7.6	30.00	16.	****	0.24	23.
22	22	52.	5.6	1.52	0.190	17.2	****	200.	7.3	*****	26.	****	0.32	25.
23	21	40.	3.1	1.80	0.080	12.2	****	120.	7.6	30.00	14.	****	0.16	28.
24	22	40.	2.8	0.96	0.130	10.8	63.	90.	7.5	*****	21.	****	0.12	29.
25	22	53.	5.9	1.08	0.150	15.4	****	182.	7.5	30.00	13.	8.	0.38	58.
26	22	35.	9.6	4.64	0.140	11.4	****	75.	7.5	*****	14.	****	0.18	43.
27	23	52.	6.1	2.52	0.190	26.7	****	164.	7.5	50.00	14.	****	0.28	24.
28	22	26.	7.6	0.84	0.150	12.5	****	55.	7.6	*****	13.	****	0.22	26.
29	22	57.	4.1	1.08	0.150	21.1	****	68.	7.6	80.00	45.	****	0.22	26.
30	28	28.	2.7	0.60	0.140	17.8	32.	185.	7.8	*****	16.	****	0.00	28.
31	28	28.	2.7	0.60	0.140	17.8	****	185.	7.8	*****	16.	****	0.00	25.
AVERAGE		54.0	18.9	2.29	0.178	28.3	70.	186.	7.6	31.16	25.5	20.5	0.31	45.5

APPENDIX C

Table 12: WATER QUALITY DATA MAY, 1971 - PROCESS WATER TERTIARY TREATMENT EFFLUENT

DATE	FLOW G/D (M)	OIL I.R. mg/1	OIL APHA mg/1	NH_3-N mg/1	PHENOL mg/1	BOD mg/1	COD mg/1	TOD mg/1	pH	TON (M)	TSS mg/1	VSS mg/1	PO_4 mg/1	TURB JTU	TEMP. °F	ALUM. mg/1	POLY. mg/1	SULF. mg/1
1	25	15.	5.0	1.04	0.250	28.1	***	82.	7.3	3.00	11.	****	0.08	11.	76.	48	.23	0
2	25	8.	2.3	0.88	0.150	10.8	***	55.	7.8	*****	10.	****	0.08	10.	75.	48	.24	0
3	26	11.	2.5	1.28	*****	9.2	65.	60.	7.4	1.50	11.	****	0.10	11.	72.	46	.23	0
4	23	20.	8.0	1.64	0.170	17.8	***	105.	7.6	*****	17.	11.	0.08	10.	74.	42	.26	0
5	29	19.	5.4	2.72	0.170	14.7	***	85.	7.6	20.00	20.	****	0.08	12.	75.	33	.21	2.1
6	23	8.	5.4	2.00	0.250	20.8	***	73.	7.4	*****	21.	****	0.12	18.	74.	47	.31	3.6
7	23	16.	3.9	3.56	*****	****	***	180.	7.5	20.00	6.	****	0.12	13.	75.	52	.37	0.6
8	25	7.	3.1	3.64	0.140	****	***	120.	7.5	*****	10.	****	0.06	13.	75.	43	.29	0
9	25	8.	4.4	1.92	0.150	10.4	***	45.	7.7	10.00	8.	****	0.00	9.	76.	38	.24	0
10	27	9.	1.9	1.84	0.100	9.1	26.	40.	7.7	*****	7.	****	0.00	6.	77.	35	.22	0
11	24	27.	4.6	1.72	0.150	15.0	***	200.	7.8	5.00	26.	15.	0.10	8.	76.	40	0	0
12	24	37.	***	3.08	0.230	18.8	***	150.	7.8	*****	30.	****	0.06	21.	74.	40	0	0
13	26	20.	6.2	4.52	0.190	31.8	***	105.	7.2	3.00	14.	****	0.12	13.	78.	37	.23	0
14	26	14.	3.9	4.64	0.230	7.8	***	45.	7.3	*****	24.	****	0.06	12.	78.	37	.23	0
15	24	12.	4.6	4.40	0.140	15.0	***	60.	7.5	3.00	11.	****	0.02	9.	79.	40	.25	0
16	24	8.	2.6	3.96	0.120	10.8	***	45.	7.5	*****	6.	****	0.12	6.	80.	40.	.25	0
17	26	10.	4.3	2.08	0.130	8.2	***	45.	7.6	4.00	8.	****	0.08	6.	78.	37	.23	0
18	26	25.	***	4.92	0.120	11.8	***	80.	7.5	*****	18.	12.	0.02	9.	78.	37	0	2.3
19	21	17.	4.1	2.28	0.150	8.2	***	50.	7.6	2.00	8.	****	0.06	14.	79.	45	.40	0
20	21	11.	1.4	2.28	0.120	11.8	***	55.	7.3	*****	12.	****	0.06	8.	79.	45	.28	0
21	22	7.	1.2	1.00	0.130	13.2	***	45.	7.5	1.50	4.	****	0.04	5.	79.	43	0	0
22	22	9.	1.5	1.64	0.100	15.8	***	68.	7.2	*****	34.	****	0.10	5.	78.	33	0	0
23	21	8.	1.3	1.92	0.100	11.8	***	40.	7.4	4.00	10.	****	0.04	6.	80.	34	0	0
24	22	8.	0.8	1.00	0.100	12.7	26.	45.	7.4	*****	14.	****	0.02	6.	80.	33	0	0
25	22	11.	1.6	1.04	0.120	11.4	***	60.	7.4	4.00	10.	8.	0.04	10.	79.	33	0	1.7
26	22	8.	1.2	4.04	0.100	13.5	***	45.	7.5	*****	6.	****	0.02	5.	77.	33	0	0
27	23	12.	1.6	2.28	0.150	24.6	***	60.	7.4	15.00	8.	****	0.02	5.	78.	31	0	0
28	22	8.	1.2	0.80	0.140	15.8	***	35.	7.7	*****	8.	****	0.06	5.	81.	33	0	0
29	22	8.	0.6	1.16	0.120	15.8	***	40.	7.6	1.75	15.	****	0.00	5.	82.	33	0	0
30	23	13.	0.8	0.40	0.140	15.4	7.	35.	7.8	*****	***	****	0.00	5.	84.	31	0	0
31	28	13.	0.8	0.40	0.140	15.4	***	35.	7.8	*****	***	****	0.00	5.	***	26	0	0
AVERAGE		13.1	2.9	2.26	0.148	14.6	31.	70.	7.5	6.51	13.3	11.5	0.05	9.0	77.			

APPENDIX C

Table 13: WATER QUALITY DATA JUNE, 1971 - PROCESS WATER API SEPARATOR EFFLUENT

DATE	FLOW G/D (M)	OIL I.R. mg/l	OIL APHA mg/l	NH_3-N mg/l	PHENOL mg/l	BOD mg/l	COD mg/l	TOD mg/l	pH	TON (M)	TSS mg/l	VSS mg/l	PO_4 mg/l
1	25	55.		1.14	0.250	10.0	****	78.	7.5	70.00	12.	****	1.12
2	25	55.		1.14	0.250	10.0	****	78.	7.5	70.00	12.	****	1.12
3	24	98.		1.08	0.290	59.4	****	205.	7.4	60.00	26.	****	1.22
4	26	98.		1.08	0.290	59.4	****	205.	7.4	60.00	26.	****	1.22
5	29	76.		1.54	0.210	72.8	****	235.	7.7	60.00	33.	****	0.32
6	31	76.		1.54	0.210	72.8	****	235.	7.7	60.00	33.	****	0.32
7	30	177.		1.50	0.170	32.2	49.	130.	7.6	60.00	15.	13.	1.18
8	29	177.		1.50	0.170	32.2	49.	130.	7.6	60.00	15.	13.	1.18
9	26	176.		1.82	0.290	110.5	****	320.	7.3	50.00	27.	****	1.08
10	26	176.		1.82	0.200	110.5	****	320.	7.3	50.00	27.	****	1.08
11	26	132.		1.78	0.290	102.2	****	260.	7.5	40.00	27.	****	0.54
12	29	132.		1.78	0.290	102.2	****	260.	7.5	40.00	27.	****	0.54
13	28	51.		0.92	0.130	38.9	16.	100.	7.5	80.00	16.	****	0.22
14	27	51.		0.92	0.130	38.9	16.	100.	7.5	80.00	16.	****	0.22
15	26	121.		2.46	0.550	89.4	****	208.	7.7	50.00	31.	24.	1.40
16	26	121.		2.46	0.550	89.4	****	208.	7.7	50.00	31.	24.	1.40
17	25	242.		2.90	0.130	70.5	****	290.	7.3	60.00	51.	****	0.60
18	25	242.		2.90	0.130	70.5	****	290.	7.3	60.00	51.	****	0.60
19	25	100.		3.30	0.900	75.0	****	180.	7.6	80.00	26.	****	0.56
20	25	100.		3.30	0.900	70.0	****	310.	7.6	80.00	26.	****	0.56
21	25	33.		3.00	0.540	49.4	20.	162.	7.6	70.00	21.	20.	1.00
22	23	33.		3.00	0.540	49.4	20.	1.	7.6	70.00	21.	20.	1.00
23	24	26.		2.74	0.660	68.9	****	****	7.7	100.00	12.	****	0.56
24	30	26.		2.74	0.660	68.9	****	****	7.7	100.00	12.	****	0.56
25	30	31.		5.16	0.640	176.6	****	355.	7.5	90.00	31.	****	0.56
26	28	110.		2.32	*****	105.5	****	****	7.8	90.00	34.	****	0.46
27	31	110.		2.32	*****	105.5	****	310.	7.8	90.00	34.	****	0.46
28	32	202.		1.78	0.360	159.4	118.	425.	8.0	90.00	31.	16.	0.66
29	28	202.		1.78	0.360	159.4	118.	425.	8.0	90.00	31.	16.	0.66
30	26	999.		2.20	0.310	108.9	****	185.	7.7	175.00	32.	****	0.08
AVERAGE		140.9		2.13	0.371	78.9	50.	222.	7.6	72.83	26.2	18.2	0.74

APPENDIX C

Table 14: WATER QUALITY DATA JUNE, 1971 - PROCESS WATER BIOPOND EFFLUENT

DATE	FLOW G/D (MM)	OIL I.R. mg/l	OIL APHA mg/l	NH_3-N mg/l	PHENOL mg/l	BOD mg/l	COD mg/l	TOD mg/l	pH	TON (M)	TSS mg/l	VSS mg/l	PO_4 mg/l	TURB. JTU
1	25	38.	9.0	1.80	0.150	14.5	****	55.	7.4	60.00	10.	7.	0.24	34.
2	25	38.	8.0	0.86	0.210	20.0	****	92.	7.6	******	7.	****	0.16	51.
3	24	74.	28.0	0.68	0.230	41.1	****	210.	7.5	50.00	****	****	0.42	48.
4	26	56.	16.0	0.92	0.230	32.5	****	135.	7.4	******	17.	****	0.36	49.
5	29	66.	25.6	1.30	0.140	37.2	****	235.	7.7	40.00	32.	****	0.34	42.
6	31	49.	9.4	1.34	0.140	15.3	****	130.	7.6	******	15.	****	0.50	42.
7	30	79.	19.1	1.42	0.190	23.6	117.	210.	7.8	40.00	13.	****	0.58	101.
8	29	64.	9.0	1.46	0.150	24.7	****	150.	7.6	******	18.	11.	0.46	101.
9	26	68.	35.1	1.30	0.210	36.9	****	200.	7.7	40.00	29.	****	0.50	49.
10	26	92.	57.7	1.50	0.380	65.9	****	290.	7.4	******	34.	****	0.52	50.
11	26	58.	20.1	0.16	0.250	40.9	****	102.	7.5	70.00	16.	****	0.34	50.
12	29	75.	33.9	1.82	0.150	49.5	****	230.	7.5	******	30.	****	0.60	45.
13	28	33.	9.0	0.74	0.150	20.0	****	98.	7.6	40.00	14.	****	0.18	32.
14	27	37.	12.6	0.64	0.130	23.4	61.	133.	7.5	******	15.	****	0.18	25.
15	26	40.	13.8	0.74	0.120	28.9	****	168.	7.5	30.00	17.	8.	0.32	34.
16	26	106.	26.2	2.08	0.210	48.6	****	120.	7.3	******	44.	****	0.22	55.
17	25	103.	40.9	2.82	0.250	36.1	****	235.	7.6	30.00	27.	****	0.46	75.
18	25	190.	88.5	2.74	0.110	27.5	****	355.	7.1	100.00	57.	****	0.52	76.
19	25	133.	58.3	3.08	0.150	64.8	****	300.	7.2	******	27.	****	0.46	73.
20	25	53.	15.0	3.30	0.130	120.0	****	140.	7.3	40.00	11.	****	0.14	65.
21	25	67.	15.3	2.05	0.290	63.9	102.	230.	7.4	******	14.	****	0.54	55.
22	23	101.	42.2	2.58	0.250	83.1	****	370.	7.4	60.00	27.	17.	0.50	100.
23	24	120.	25.7	2.66	*****	43.4	****	230.	7.6	******	19.	****	0.88	95.
24	30	89.	14.4	2.82	0.340	64.2	****	250.	7.4	70.00	13.	****	1.44	86.
25	30	131.	10.5	2.40	0.150	53.3	****	195.	7.6	******	15.	****	1.18	96.
26	28	32.	6.0	2.58	0.140	27.2	****	88.	7.7	40.00	11.	****	1.26	62.
27	31	32.	6.0	2.58	0.140	27.2	****	88.	7.7	******	11.	****	1.26	45.
28	32	51.	13.3	1.88	0.140	43.3	91.	155.	7.7	******	15.	****	1.66	37.
29	28	307.	****	1.68	0.340	138.7	****	1000.	7.7	25.00	78.	38.	1.32	63.
30	26	112.	61.9	1.62	0.250	80.8	****	273.	7.7	******	43.	****	1.48	103.
AVERAGE		83.2	25.1	1.78	0.197	46.5	92.	215.	7.5	40.00	23.4	16.2	0.63	61.3

APPENDIX C

Table 15: WATER QUALITY DATA JUNE, 1971 - PROCESS WATER TERTIARY TREATMENT EFFLUENT

DATE	FLOW G/D (M)	OIL		NH_3-N mg/1	PHENOL mg/1	BOD mg/1	COD mg/1	TOD mg/1	pH	TON (M)	TSS mg/1	VSS mg/1	PO_4 mg/1	TURB. JTU	TEMP. °F	ALUM. mg/1	POLY. mg/1	SULF. mg/1
		I.R. mg/1	APHA mg/1															
1	25	8.	2.2	1.36	0.150	15.4	***	40.	7.4	25.00	10.	8.	0.02	6.	84.	29	0	0
2	25	14.	1.6	0.74	0.120	13.6	***	50.	7.6	*****	10.	****	0.06	9.	84.	29	0	0
3	24	10.	2.7	0.60	0.130	20.4	***	70.	7.4	20.00	6.	****	0.02	9.	85.	30	0	0
4	26	11.	1.5	1.00	0.110	21.0	***	50.	7.5	*****	9.	****	0.04	10.	86.	28	0	0
5	29	18.	7.2	1.22	0.100	18.6	***	150.	7.7	17.50	38.	****	0.06	10.	88.	25	.21	0
6	31	15.	3.3	1.26	0.140	13.2	***	90.	7.6	*****	21.	****	0.12	11.	89.	23	.19	0
7	30	21.	4.2	1.38	0.120	11.8	8.	60.	7.7	15.00	8.	****	0.16	17.	88.	28	.20	0
8	29	15.	1.6	1.46	0.130	13.6	***	50.	7.6	*****	14.	8.	0.06	18.	85.	25	.33	0
9	26	11.	0.2	1.22	0.140	7.2	***	35.	7.7	12.50	8.	****	0.04	9.	86.	28	.28	0
10	26	22.	6.1	1.42	0.170	26.8	***	80.	7.2	*****	10.	****	0.06	12.	87.	40	.23	0
11	26	13.	4.6	1.58	0.150	23.6	***	105.	7.5	10.00	7.	****	0.06	12.	87.	41	.23	0
12	29	19.	6.8	1.94	0.150	23.9	***	80.	7.4	*****	28.	****	0.12	9.	87.	33	.21	0
13	28	12.	2.0	0.80	0.140	17.7	***	50.	7.6	6.00	9.	****	0.02	11.	90.	39	.21	0
14	27	10.	1.5	0.50	0.110	14.5	6.	55.	7.5	*****	9.	****	0.00	6.	88.	40	.22	1.6
15	26	14.	1.8	0.50	0.120	18.6	***	82.	7.4	5.00	15.	14.	0.06	8.	89.	41	.23	8.8
16	26	21.	3.6	2.08	0.250	18.5	***	72.	7.2	*****	22.	****	0.06	15.	90.	45	.23	9.1
17	25	24.	4.4	2.90	0.250	12.7	***	110.	7.6	10.00	14.	****	0.08	17.	89.	47	.29	8.8
18	25	54.	15.1	2.74	0.120	20.8	***	155.	7.1	5.00	36.	****	0.14	20.	88.	47	.29	8.8
19	25	44.	14.0	3.08	0.090	26.3	***	145.	7.1	*****	24.	****	0.12	34.	88.	47	.29	0
20	25	27.	3.0	3.30	0.170	12.2	***	75.	7.2	8.00	8.	****	0.06	15.	90.	43	.29	0
21	25	27.	2.6	2.46	0.270	16.8	23.	105.	7.3	*****	7.	****	0.18	21.	88.	43	.29	2.1
22	23	21.	2.5	2.90	0.170	12.2	***	108.	7.2	8.00	13.	9.	0.06	17.	88.	25	.31	8.0
23	24	13.	1.8	3.00	*****	8.2	***	70.	7.5	*****	11.	****	0.14	27.	88.	20	.30	7.9
24	30	22.	3.9	2.94	0.190	21.1	***	90.	7.4	10.00	9.	****	0.16	18.	92.	36	.24	8.8
25	30	23.	1.8	2.46	0.210	23.5	***	70.	7.5	*****	7.	****	0.06	30.	91.	45	.32	8.2
26	28	29.	3.0	2.32	0.130	21.3	***	50.	7.7	10.00	8.	****	0.06	11.	90.	45	.26	0
27	31	29.	3.0	2.32	0.130	21.3	***	50.	7.7	*****	8.	****	0.06	11.	***	39	.19	-
28	32	20.	2.1	1.82	0.140	27.2	59.	70.	7.7	*****	8.	****	0.12	13.	96.	34	.19	2.1
29	28	117.	49.9	1.54	0.230	47.8	***	530.	7.7	15.00	48.	30.	0.20	24.	94.	42	.21	9.2
30	26	38.	11.5	1.78	0.190	28.5	***	100.	7.7	*****	29.	****	0.14	48.	94.	51	.37	8.8
AVERAGE		24.0	5.6	1.82	0.155	19.2	24.	94.	7.4	11.80	15.1	13.8	0.08	15.9	88.			

APPENDIX C

Table 16: WATER QUALITY DATA JULY, 1971 - PROCESS WATER API SEPARATOR EFFLUENT

DATE	FLOW G/D (M)	OIL		NH_3-N mg/l	PHENOL mg/l	BOD mg/l	COD mg/l	TOD mg/l	pH	TON (M)	TSS mg/l	VSS mg/l	PO_4 mg/l
		I.R. mg/l	APHA mg/l										
1	28	990.		2.20	0.310	108.9	****	185.	7.7	175.00	32.	****	0.82
2	26	330.		2.20	0.640	87.8	****	280.	7.2	60.00	22.	****	0.54
3	26	330.		2.20	0.640	87.8	****	280.	7.2	60.00	22.	****	0.54
4	34	87.		1.88	0.900	46.1	****	305.	7.8	50.00	34.	****	0.22
5	26	87.		1.88	0.900	46.1	****	305.	7.8	50.00	34.	****	0.22
6	28	338.		2.14	0.430	163.8	167.	422.	7.7	50.00	44.	29.	0.42
7	28	338.		2.14	0.430	163.8	167.	422.	7.7	50.00	44.	29.	0.42
8	27	251.		2.08	0.270	108.3	****	215.	7.4	40.00	30.	****	0.34
9	28	251.		2.08	0.270	108.3	****	215.	7.4	40.00	30.	****	0.34
10	28	87.		2.14	1.600	110.5	****	238.	8.0	80.00	20.	****	0.74
11	28	87.		2.14	1.600	110.5	****	238.	8.0	80.00	20.	****	0.74
12	28	54.		1.78	0.120	68.9	****	88.	7.3	50.00	****	****	0.58
13	28	54.		1.78	0.120	68.9	****	88.	7.3	50.00	****	****	0.58
14	29	133.		1.58	0.190	95.0	****	105.	7.4	100.00	11.	****	0.58
15	29	133.		1.58	0.190	95.0	****	105.	***	100.00	11.	****	0.58
16	29	159.		1.94	0.360	115.5	****	190.	7.6	50.00	22.	****	0.60
17	32	159.		1.94	0.360	115.5	****	190.	7.6	50.00	22.	****	0.60
18	30	61.		1.38	0.290	134.4	****	110.	7.9	******	14.	****	0.32
19	31	61.		1.38	0.290	134.4	****	110.	7.9	******	14.	****	0.32
20	32	59.		1.68	0.270	147.7	****	120.	7.4	80.00	****	****	0.74
21	32	59.		1.68	0.270	147.7	****	120.	7.4	80.00	****	****	0.74
22	32	50.		1.22	0.210	52.8	****	90.	7.5	60.00	15.	****	0.58
23	32	50.		1.22	0.210	52.8	****	90.	7.5	60.00	15.	****	0.58
24	32	69.		1.10	0.250	89.4	****	138.	7.7	70.00	14.	****	0.56
25	32	69.		1.10	0.250	89.4	****	138.	7.7	70.00	14.	****	0.56
26	32	42.		1.50	0.100	48.9	****	****	7.6	70.00	30.	15.	0.54
27	32	42.		1.50	0.100	48.9	****	****	7.6	70.00	30.	15.	0.54
28	32	57.		1.90	0.100	25.0	****	105.	7.5	60.00	13.	****	0.30
29	32	57.		1.90	0.100	25.0	****	105.	7.5	60.00	13.	****	0.30
30	32	56.		2.14	0.390	62.8	****	175.	7.5	90.00	22.	****	0.18
31	32	99.		2.14	0.390	62.8	****	175.	7.5	90.00	22.	****	0.18
AVERAGE		151.9		1.79	0.404	91.0	167.	184.	7.5	68.79	22.7	22.0	0.49

APPENDIX C

Table 17: WATER QUALITY DATA JULY, 1971 - PROCESS WATER BIOPOND EFFLUENT

DATE	FLOW G/D (MM)	OIL I.R. mg/l	OIL APHA mg/l	NH_3-N mg/l	PHENOL mg/l	BOD mg/l	COD mg/l	TOD mg/l	pH	TON (M)	TSS mg/l	VSS mg/l	PO_4 mg/l	TURB. JTU
1	28	101.	50.3	1.88	0.380	80.3		268.	7.6	30.00	28.	****	0.64	55.
2	26	62.	39.1	1.88	0.210	47.8		270.	7.4	25.00	18.	****	0.22	135.
3	26	62.	39.1	1.88	0.210	47.8		270.	7.4	25.00	18.	****	****	55.
4	34	19.	6.7	1.68	0.110	16.4		105.	7.8	30.00	****	****	0.54	39.
5	26	19.	6.7	1.68	0.110	16.4		105.	7.8	30.00	****	****	****	49.
6	28	130.	59.7	1.62	0.270	58.9		98.	7.5	*****	24.	10.	0.36	45.
7	28	131.	55.4	1.94	0.230	56.1		350.	7.5	25.00	26.	****	0.60	51.
8	27	140.	65.4	2.02	0.210	80.3		375.	7.7	*****	29.	****	0.58	166.
9	28	121.	37.1	1.78	0.250	64.7		178.	7.5	50.00	24.	****	0.36	174.
10	28	70.	17.8	1.54	0.170	39.4		140.	7.9	40.00	13.	****	0.34	133.
11	28	70.	17.8	1.54	0.170	39.4		140.	7.9	40.00	13.	****	****	69.
12	28	54.	12.6	1.72	0.190	35.3		120.	7.4	*****	22.	****	0.54	39.
13	28	45.	12.9	1.68	0.130	30.3		115.	7.3	15.00	10.	10.	0.28	39.
14	29	53.	8.1	1.00	0.130	72.5		165.	7.4	*****	13.	****	0.26	34.
15	29	96.	48.0	1.10	0.140	44.7		128.	7.4	25.00	33.	****	0.58	50.
16	29	64.	13.6	1.58	0.290	27.2		120.	7.5	*****	20.	****	0.22	52.
17	32	89.	39.5	1.62	0.250	55.8		235.	7.5	80.00	32.	****	0.44	51.
18	30	85.	31.1	1.54	0.270	44.5		175.	7.4	*****	18.	****	0.16	47.
19	31	68.	14.4	1.18	0.230	62.2		112.	7.8	*****	16.	****	0.28	64.
20	32	71.	18.0	1.22	0.190	34.7		160.	7.6	60.00	27.	25.	0.64	59.
21	32	69.	19.2	1.46	0.360	35.7		312.	7.6	*****	16.	****	0.36	65.
22	32	39.	11.3	1.26	0.170	15.6		100.	7.6	30.00	11.	****	0.18	57.
23	32	63.	8.9	1.38	0.210	32.8		90.	7.5	*****	17.	****	0.14	57.
24	32	92.	48.9	5.00	0.230	65.3		310.	7.5	25.00	32.	****	0.28	74.
25	32	48.	14.4	1.32	0.170	30.9		132.	7.6	*****	10.	****	0.20	61.
26	32	56.	17.2	0.90	0.270	28.9		128.	7.9	25.00	****	****	0.08	63.
27	32	49.	15.3	1.20	0.100	27.2		130.	7.8	*****	26.	12.	0.18	53.
28	32	40.	10.7	1.72	0.190	39.7		121.	8.0	50.00	13.	****	0.18	45.
29	32	69.	5.6	2.00	0.100	4.7		80.	7.6	*****	14.	****	0.36	42.
30	32	*****	12.8	1.54	0.130	8.9		120.	7.5	40.00	33.	****	0.20	44.
31	32	82.	42.8	2.02	0.230	26.7		185.	7.6	*****	40.	****	0.22	46.
AVERAGE		71.9	25.8	1.67	0.203	41.0		172.	7.6	35.83	21.3	14.2	0.33	64.9

APPENDIX C

Table 18: WATER QUALITY DATA JULY, 1971 - PROCESS WATER TERTIARY TREATMENT EFFLUENT

DATE	FLOW G/D (M)	OIL		NH$_3$-N mg/1	PHENOL mg/1	BOD mg/1	COD mg/1	TOD mg/1	pH	TON (M)	TSS mg/1	VSS mg/1	PO$_4$ mg/1	TURB. JTU	TEMP. °F	ALUM. mg/1	POLY. mg/1	SULF. mg/1
		I.R. mg/1	APHA mg/1															
1	28	33.	5.7	1.94	0.190	34.3		82.	7.4	6.00	14.	****	0.06	9.	94.	75	0.21	9.2
2	26	35.	7.7	1.88	0.150	19.1		110.	7.2	3.00	****	****	0.04	13.	95.	75	0.37	5.8
3	26	35.	7.7	1.88	0.150	19.1		110.	7.2	3.00	****	****	0.04	13.	***	64	0.25	0.0
4	34	11.	2.3	1.42	0.140	12.2		60.	7.7	5.00	8.	****	0.06	6.	94.	44	0.18	0.0
5	26	11.	2.3	1.42	0.140	12.2		60.	7.7	5.00	8.	****	0.06	11.	***	50	0.23	0.0
6	28	34.	***	1.68	0.150	18.6		68.	7.5	*****	8.	****	0.10	11.	95.	58	0.22	0.0
7	28	30.	7.3	1.78	0.170	43.2		120.	7.4	5.00	19.	****	0.14	16.	96.	48	0.10	2.7
8	27	26.	5.9	1.98	0.110	51.3		108.	7.7	*****	13.	****	0.14	20.	94.	60	0.18	5.6
9	28	27.	6.8	1.82	0.140	33.0		52.	7.4	5.00	15.	****	0.10	10.	93.	50	0.21	0.0
10	28	20.	4.2	1.50	0.170	28.9		60.	7.9	4.00	10.	****	0.14	11.	93.	51	0.21	0.0
11	28	20.	4.2	1.50	0.170	28.9		60.	7.9	4.00	10.	****	0.14	9.	***	50	0.17	0.0
12	28	18.	2.7	1.62	0.120	25.5		55.	7.4	*****	8.	****	0.06	9.	93.	49	0.17	0.0
13	28	12.	3.9	1.94	0.120	23.5		53.	7.2	4.00	7.	6.	0.10	10.	93.	42	0.17	0.0
14	29	12.	***	1.04	0.110	42.3		98.	7.4	*****	9.	****	0.02	11.	93.	40	0.16	0.0
15	29	34.	4.9	1.18	0.100	16.4		62.	7.5	9.00	14.	****	0.24	16.	93.	40	0.16	0.0
16	29	23.	2.0	1.50	0.110	14.7		68.	7.5	*****	9.	****	0.20	13.	93.	44	0.16	0.0
17	32	23.	7.6	1.58	0.140	15.2		115.	7.4	10.00	7.	****	0.14	18.	91.	37	0.15	0.0
18	30	19.	6.8	1.58	0.100	11.0		75.	7.4	*****	9.	****	0.18	15.	92.	39	0.16	0.0
19	31	17.	6.3	0.92	0.170	15.8		81.	7.8	*****	14.	****	0.14	18.	92.	38	0.14	0.0
20	32	14.	4.6	1.26	0.120	14.1		68.	7.6	10.00	13.	10.	0.16	12.	91.	38	0.14	0.0
21	32	16.	3.7	1.38	0.150	23.6		75.	7.7	*****	8.	****	0.12	14.	91.	41	0.16	0.0
22	32	10.	3.8	1.22	0.100	13.2		40.	7.6	5.00	8.	****	0.10	13.	92.	45	0.18	0.0
23	32	13.	1.7	1.22	0.140	9.5		52.	7.4	*****	6.	****	0.10	12.	91.	47	0.20	0.0
24	32	25.	7.3	1.38	0.140	8.6		110.	7.4	20.00	16.	****	0.10	18.	91.	46	0.18	0.0
25	32	13.	1.9	0.54	0.110	13.1		55.	7.6	*****	7.	****	0.08	19.	93.	35	0.19	0.0
26	32	12.	1.6	0.90	0.170	13.9		55.	7.8	4.00	8.	****	0.10	16.	92.	45	0.18	0.0
27	32	12.	5.0	1.10	0.100	14.9		40.	7.7	*****	10.	****	0.10	14.	93.	41	0.20	0.0
28	32	10.	2.6	1.50	0.120	8.2		40.	7.9	3.00	6.	****	0.06	13.	91.	42	0.19	0.0
29	32	25.	2.6	1.90	0.100	8.2		60.	7.4	*****	12.	****	0.12	12.	93.	39	0.18	0.0
30	32	****	***	****	*****	****		****	***	*****	****	****	****	12.	90.	41	0.16	1.7
31	32	20.	6.8	1.88	0.130	6.3		70.	7.5	*****	10.	****	0.08	12.	92.	39	0.16	0.0
AVERAGE		20.3	4.6	1.48	0.134	19.9		72.	7.5	6.05	10.2	8.0	0.10	13.0	92.			

APPENDIX C

Table 19: WATER QUALITY DATA JULY, 1971 - PROCESS WATER API SEPARATOR EFFLUENT

DATE	FLOW G/D MM	OIL		NH_3-N mg/l	PHENOL mg/l	BOD mg/l	TOD mg/l	pH	TON (M)	TSS mg/l	VSS mg/l	PO_4 mg/l
		I.R. mg/l	APHA mg/l									
1	28.	999.	****	2.20	0.310	108.9	185.	7.7	175.00	32.	****	0.82
2	****	330.	****	2.20	0.640	87.8	280.	7.2	60.00	22.	****	0.54
3	****	330.	****	2.20	0.640	87.8	280.	7.2	60.00	22.	****	0.54
4	****	87.	****	1.88	0.900	46.1	305.	7.8	50.00	34.	****	0.22
5	****	87.	****	1.88	0.900	46.1	305.	7.8	50.00	34.	****	0.22
6	****	338.	****	2.14	0.430	163.8	422.	7.7	50.00	44.	29.	0.42
7	****	338.	****	2.14	0.430	163.8	422.	7.7	50.00	44.	29.	0.42
8	****	251.	****	2.08	0.270	108.3	215.	7.4	40.00	30.	****	0.34
9	28.	251.	****	2.08	0.270	108.3	215.	7.4	40.00	30.	****	0.34
10	****	87.	****	2.14	1.600	110.5	238.	8.0	80.00	20.	****	0.74
11	****	87.	****	2.14	1.600	110.5	238.	8.0	80.00	20.	****	0.74
12	****	54.	****	1.78	0.120	68.9	88.	7.3	50.00	****	****	0.58
13	****	54.	****	1.78	0.120	68.9	88.	7.3	50.00	****	****	0.58
14	29.	133.	****	1.58	0.190	95.0	105.	7.4	100.00	11.	****	0.58
15	****	133.	****	1.58	0.190	95.0	105.	***	100.00	11.	****	0.58
16	****	159.	****	1.94	0.360	115.5	190.	7.6	50.00	22.	****	0.60
17	****	159.	****	1.94	0.360	115.5	190.	7.6	50.00	22.	****	0.60
18	****	61.	****	1.38	0.290	134.4	110.	7.9	******	14.	****	0.32
19	****	61.	****	1.38	0.290	134.4	110.	7.9	******	14.	****	0.32
20	****	59.	****	1.68	0.270	147.7	120.	7.4	80.00	****	****	0.74
21	29.	59.	****	1.68	0.270	147.7	120.	7.4	80.00	****	****	0.74
22	****	50.	****	1.22	0.210	52.8	90.	7.5	60.00	15.	****	0.58
23	****	50.	****	1.22	0.210	52.8	90.	7.5	60.00	15.	****	0.58
24	****	69.	****	1.10	0.250	89.4	138.	7.7	70.00	14.	****	0.56
25	****	69.	****	1.10	0.250	89.4	138.	7.7	70.00	14.	****	0.56
26	****	42.	****	1.50	0.100	48.9	****	7.6	70.00	30.	15.	0.54
27	32.	42.	****	1.50	0.100	48.9	****	7.6	70.00	30.	15.	0.54
28	****	57.	****	1.90	0.100	25.0	105.	7.5	60.00	13.	****	0.30
29	****	57.	****	1.90	0.100	25.0	105.	7.5	60.00	13.	****	0.30
30	****	56.	****	2.14	0.390	62.8	175.	7.5	90.00	22.	****	0.18
31	****	99.	****	2.14	0.390	62.8	175.	7.5	90.00	22.	****	0.18
AVERAGE	29.	151.9	0.0	1.79	0.404	91.0	184.	7.5	68.79	22.7	22.0	0.49

APPENDIX C

Table 20: WATER QUALITY DATA JULY, 1971 - PROCESS WATER BIOPOND EFFLUENT

DATE	FLOW G/D (MM)	OIL I.R. mg/l	OIL APHA mg/l	NH_3-N mg/l	PHENOL mg/l	BOD mg/l	TOD mg/l	pH	TON (M)	TSS mg/l	VSS mg/l	PO_4 mg/l	TURB. JTU
1	28.	101.	50.3	1.88	0.380	80.3	268.	7.6	30.00	28.	****	0.64	55.
2	****	62.	39.1	1.88	0.210	47.8	270.	7.4	25.00	18.	****	0.22	135.
3	****	62.	39.1	1.88	0.210	47.8	270.	7.4	25.00	18.	****	****	55.
4	****	19.	6.7	1.68	0.110	16.4	105.	7.8	30.00	****	****	0.54	39.
5	****	19.	6.7	1.68	0.110	16.4	105.	7.8	30.00	****	****	****	49.
6	****	130.	59.7	1.62	0.270	58.9	98.	7.5	*****	24.	10.	0.36	45.
7	****	131.	55.4	1.94	0.230	56.1	350.	7.5	25.00	26.	****	0.60	51.
8	****	140.	65.4	2.02	0.210	80.3	375.	7.7	*****	29.	****	0.58	166.
9	28.	121.	37.1	1.78	0.250	64.7	178.	7.5	50.00	24.	****	0.36	174.
10	****	70.	17.8	1.54	0.170	39.4	140.	7.9	40.00	13.	****	0.34	133.
11	****	70.	17.8	1.54	0.170	39.4	140.	7.9	40.00	13.	****	****	69.
12	****	54.	12.6	1.72	0.190	35.3	120.	7.4	*****	22.	****	0.54	39.
13	****	45.	12.9	1.68	0.130	30.3	115.	7.3	15.00	10.	10.	0.28	39.
14	29.	53.	8.1	1.00	0.130	72.5	165.	7.4	*****	13.	****	0.26	34.
15	****	96.	48.0	1.10	0.140	44.7	128.	7.4	25.00	33.	****	0.58	50.
16	****	64.	13.6	1.58	0.290	27.2	120.	7.5	*****	20.	****	0.22	52.
17	****	89.	39.5	1.62	0.250	55.8	235.	7.5	80.00	32.	****	0.44	51.
18	****	85.	31.1	1.54	0.270	44.5	175.	7.4	*****	18.	****	0.16	47.
19	****	68.	14.4	1.18	0.230	62.2	112.	7.8	*****	16.	****	0.28	64.
20	****	71.	18.0	1.22	0.190	34.7	160.	7.6	60.00	27.	25.	0.64	59.
21	29.	69.	19.2	1.46	0.360	35.7	312.	7.6	*****	16.	****	0.36	65.
22	****	39.	11.3	1.26	0.170	15.6	100.	7.6	30.00	11.	****	0.18	57.
23	****	63.	8.9	1.38	0.210	32.8	90.	7.5	*****	17.	****	0.14	57.
24	****	92.	48.9	5.00	0.230	65.3	310.	7.5	25.00	32.	****	0.28	74.
25	****	48.	14.4	1.32	0.170	30.9	132.	7.6	*****	10.	****	0.20	61.
26	****	56.	17.2	0.90	0.270	28.9	128.	7.9	25.00	****	****	0.08	63.
27	32.	49.	15.3	1.20	0.100	27.2	130.	7.8	*****	26.	12.	0.18	53.
28	****	40.	10.7	1.72	0.190	39.7	121.	8.0	50.00	13.	****	0.18	45.
29	****	69.	5.6	2.00	0.100	4.7	80.	7.6	*****	14.	****	0.36	42.
30	****	*****	12.8	1.54	0.130	8.9	120.	7.5	40.00	33.	****	0.20	44
31	****	82.	42.8	2.02	0.230	26.7	185.	7.6	*****	40.	****	0.22	46.
AVERAGE	29.	71.9	25.8	1.67	0.203	41.0	172.	7.6	35.83	21.3	14.2	0.33	64.9

APPENDIX C

Table 21: WATER QUALITY DATA JULY, 1971 - PROCESS WATER TERTIARY TREATMENT EFFLUENT

DATE	FLOW G/D (MM)	OIL I.R. mg/l	OIL APHA mg/l	NH_3-N mg/l	PHENOL mg/l	BOD mg/l	TOD mg/l	pH	TON (M)	TSS mg/l	VSS mg/l	PO_4 mg/l	TURB. JTU	TEMP. °F.
1	28.	33.	5.7	1.94	0.190	34.3	82.	7.4	6.00	14.	****	0.06	9.	94.
2	****	35.	7.7	1.88	0.150	19.1	110.	7.2	3.00	****	****	0.04	13.	95.
3	****	35.	7.7	1.88	0.150	19.1	110.	7.2	3.00	****	****	0.04	13.	****
4	****	11.	2.3	1.42	0.140	12.2	60.	7.7	5.00	8.	****	0.06	6.	94.
5	****	11.	2.3	1.42	0.140	12.2	60.	7.7	5.00	8.	****	0.06	11.	****
6	****	34.	****	1.68	0.150	18.6	68.	7.5	*****	8.	****	0.10	11.	95.
7	****	30.	7.3	1.78	0.170	43.2	120.	7.4	3.00	19.	****	0.14	16.	96.
8	****	26.	5.9	1.98	0.110	51.3	108.	7.7	*****	13.	****	0.14	20.	94.
9	28.	27.	6.8	1.82	0.140	33.0	52.	7.4	5.00	15.	****	0.10	10.	93.
10	****	20.	4.2	1.50	0.170	28.9	60.	7.9	4.00	10.	****	0.14	11.	93.
11	****	20.	4.2	1.50	0.170	28.9	60.	7.9	4.00	10.	****	0.14	9.	****
12	****	18.	2.7	1.62	0.120	25.5	55.	7.4	*****	8.	****	0.06	9.	93.
13	****	12.	3.9	1.94	0.120	23.5	53.	7.2	4.00	7.	6.	0.10	10.	93.
14	29.	12.	****	1.04	0.110	42.3	98.	7.4	*****	9.	****	0.02	11.	93.
15	****	34.	4.9	1.18	0.100	16.4	62.	7.5	9.00	14.	****	0.24	16.	93.
16	****	23.	2.0	1.50	0.110	14.7	68.	7.5	*****	9.	****	0.20	13.	93.
17	****	23.	7.6	1.58	0.140	15.2	115.	7.4	10.00	7.	****	0.14	18.	91.
18	****	19.	6.8	1.58	0.100	11.0	75.	7.4	*****	9.	****	0.18	15.	92.
19	****	17.	6.3	0.92	0.170	15.8	81.	7.8	*****	14.	10.	0.14	18.	92.
20	****	14.	4.6	1.26	0.120	14.1	68.	7.6	10.00	13.	****	0.16	12.	91.
21	29.	16.	3.7	1.38	0.150	23.6	75.	7.7	*****	8.	****	0.12	14.	91.
22	****	10.	3.8	1.22	0.100	13.2	40.	7.6	5.00	8.	****	0.10	13.	92.
23	****	13.	1.7	1.22	0.140	9.5	52.	7.4	*****	6.	****	0.10	12.	91.
24	****	25.	7.3	1.38	0.140	8.6	110.	7.4	20.00	16.	****	0.10	18.	91.
25	****	13.	1.9	0.54	0.110	13.1	55.	7.6	*****	7.	****	0.08	19.	93.
26	****	12.	1.6	0.90	0.170	13.9	55.	7.8	4.00	8.	****	0.10	16.	92.
27	32.	12.	5.0	1.10	0.100	14.9	40.	7.7	*****	10.	****	0.10	14.	93.
28	****	10.	2.6	1.50	0.120	8.2	40.	7.9	3.00	6.	****	0.06	13.	91.
29	****	25.	2.6	1.90	0.100	8.2	60.	7.4	*****	12.	****	0.12	12.	93.
30	****	****	****	****	*****	****	****	***	*****	****	****	****	12.	90.
31	****	20.	6.8	1.88	0.130	6.3	70.	7.5	*****	10.	****	0.08	12.	92.
AVERAGE	29.	20.3	4.6	1.48	0.134	19.9	72.	7.5	6.05	10.2	8.0	0.10	13.0	92.

APPENDIX C

Table 22: WATER QUALITY DATA AUGUST, 1971 - PROCESS WATER API SEPARATOR EFFLUENT

DATE	FLOW G/D (MM)	OIL I.R. mg/l	OIL APHA mg/l	NH_3-N mg/l	PHENOL mg/l	BOD mg/l	TOD mg/l	pH	TON (M)	TSS mg/l	VSS mg/l	PO_4 mg/l
1	32.	135.	****	1.72	0.340	64.4	302.	7.9	*****	22.	****	****
2	****	135.	****	1.72	0.340	64.4	302.	7.9	*****	22.	****	****
3	****	50.	****	3.88	0.800	47.2	190.	7.6	30.00	8.	7.	****
4	****	50.	****	3.88	0.800	47.2	190.	7.6	30.00	8.	7.	****
5	****	99.	****	4.16	0.530	85.0	165.	7.4	20.00	24.	****	****
6	****	99.	****	4.16	0.530	85.0	165.	7.4	20.00	24.	****	****
7	****	59.	****	4.52	0.530	71.7	160.	7.4	40.00	10.	****	****
8	****	59.	****	4.52	0.530	71.7	160.	7.4	40.00	10.	****	****
9	****	188.	****	3.08	0.380	23.9	100.	7.1	80.00	11.	9.	****
10	****	188.	****	3.08	0.380	82.8	100.	7.1	8.00	11.	9.	****
11	36.	140.	****	4.80	0.570	86.1	300.	7.2	70.00	16.	****	****
12	****	140.	****	4.80	0.570	86.1	300.	7.2	70.00	16.	****	****
13	****	94.	****	4.04	0.310	85.0	215.	7.1	80.00	7.	****	0.42
14	****	94.	****	4.04	0.310	85.0	215.	7.1	80.00	7.	****	****
15	****	67.	****	4.52	0.430	32.2	135.	7.0	20.00	13.	****	****
16	****	67.	****	4.52	0.430	32.2	135.	7.0	20.00	13.	****	****
17	****	*****	****	4.16	0.310	22.2	70.	7.0	25.00	8.	****	****
18	****	*****	****	4.16	0.310	22.2	70.	7.0	25.00	8.	****	****
19	****	*****	****	****	0.270	****	52.	7.2	*****	15.	****	****
20	****	*****	****	****	0.270	****	52.	7.2	*****	15.	****	****
21	****	*****	****	****	0.290	22.8	125.	7.2	*****	11.	****	****
22	****	*****	****	****	0.290	****	125.	7.2	*****	11.	****	****
23	****	*****	****	****	0.300	33.9	140.	7.0	*****	15.	****	****
24	****	*****	****	****	0.300	****	140.	7.0	*****	15.	****	****
25	****	*****	****	****	0.190	12.8	95.	***	*****	7.	****	****
26	****	*****	****	****	0.190	12.8	95.	***	*****	7.	****	****
27	32.	*****	****	****	0.200	20.0	****	***	*****	24.	****	****
28	****	*****	****	3.50	1.500	59.4	255.	7.3	70.00	25.	****	****
29	****	*****	****	3.50	1.500	59.4	255.	7.3	70.00	25.	****	****
30	****	*****	****	****	0.140	13.9	55.	7.4	*****	11.	****	****
31	****	*****	****	****	0.140	13.9	55.	7.4	*****	11.	****	****
AVERAGE	33.	104.0	0.0	3.83	0.450	49.7	157.	7.2	44.33	13.8	8.0	0.42

APPENDIX C

Table 23: WATER QUALITY DATA AUGUST, 1971 - PROCESS WATER BIOPOND EFFLUENT

DATE	FLOW G/D (MM)	OIL I.R. mg/l	OIL APHA mg/l	NH_3-N mg/l	PHENOL mg/l	BOD mg/l	TOD mg/l	pH	TON (M)	TSS mg/l	VSS mg/l	PO_4 mg/l	TURB. JTU	TEMP. °F.
1	32.	39.	11.1	2.08	0.210	3.9	130.	7.5	60.00	15.	****	****	46.	90.
2	****	68.	32.0	3.50	0.270	10.0	192.	7.6	*****	23.	****	****	50.	90.
3	****	54.	14.2	3.20	0.230	7.8	200.	7.5	50.00	13.	10.	****	67.	89.
4	****	63.	16.2	3.20	0.190	8.6	210.	7.5	*****	13.	****	****	79.	90.
5	****	57.	21.5	3.42	0.140	34.5	182.	7.6	70.00	17.	****	****	140.	90.
6	****	62.	21.3	3.88	0.150	49.7	230.	7.3	*****	21.	****	0.32	156.	92.
7	****	94.	33.3	5.52	0.230	63.6	340.	7.5	50.00	29.	****	****	112.	95.
8	****	64.	22.4	3.56	0.150	42.5	210.	7.4	*****	18.	****	****	82.	93.
9	****	58.	15.4	4.16	0.150	30.3	150.	7.2	50.00	15.	****	****	74.	95.
10	****	86.	33.2	3.16	0.120	49.2	195.	7.1	*****	22.	16.	****	47.	95.
11	36.	46.	14.2	3.28	0.170	34.5	97.	7.1	60.00	18.	****	****	41.	93.
12	****	67.	34.8	4.80	0.190	27.8	208.	7.1	*****	18.	****	****	51.	94.
13	****	42.	15.5	3.86	0.150	21.7	105.	7.3	40.00	19.	****	0.24	82.	92.
14	****	58.	27.7	4.16	0.170	44.7	215.	7.2	*****	22.	****	****	108.	93.
15	****	36.	10.0	3.96	0.130	4.2	110.	7.2	20.00	8.	****	****	38.	92.
16	****	49.	15.8	4.28	0.170	16.1	150.	7.1	*****	6.	****	****	41.	93.
17	****	61.	18.2	3.16	0.140	26.7	177.	7.1	10.00	19.	14.	****	54.	95.
18	****	63.	17.2	3.44	0.130	30.6	160.	7.1	*****	21.	****	****	36.	95.
19	****	71.	37.9	2.84	0.150	29.7	201.	7.2	40.00	35.	****	****	36.	94.
20	****	59.	17.0	3.20	0.150	30.3	132.	7.2	*****	20.	****	0.40	60.	95.
21	****	82.	38.6	3.88	*****	22.8	310.	7.1	25.00	24.	****	****	57.	95.
22	****	74.	16.3	3.24	0.130	22.5	200.	7.2	*****	****	****	****	67.	96.
23	****	50.	16.2	2.76	0.110	12.0	150.	7.1	*****	11.	****	****	64.	95.
24	****	55.	17.6	3.20	0.200	15.0	125.	7.0	12.50	16.	14.	****	46.	96.
25	****	****	18.5	2.70	0.100	18.9	150.	7.4	*****	13.	****	****	40.	91.
26	****	81.	15.3	2.16	0.130	13.9	160.	7.6	40.00	26.	****	****	48.	95.
27	32.	69.	14.9	2.30	0.120	12.5	145.	7.3	*****	17.	****	0.20	44.	90.
28	****	44.	11.2	3.50	0.130	8.4	109.	7.5	25.00	****	****	****	46.	93.
29	****	44.	11.2	3.50	0.130	8.4	109.	7.5	25.00	****	****	****	47.	****
30	****	51.	17.0	3.00	0.130	22.3	154.	7.4	*****	26.	****	****	47.	94.
31	****	48.	17.1	1.52	0.120	18.4	146.	7.5	40.00	17.	14.	****	46	95.
AVERAGE	33.	59.8	20.0	3.36	0.156	23.9	172.	7.3	38.59	18.6	13.6	0.29	62.9	93.

APPENDIX C

Table 24: WATER QUALITY DATA AUGUST, 1971 - PROCESS WATER TERTIARY TREATMENT EFFLUENT

DATE	FLOW G/D (MM)	APHA OIL mg/l	NH_3-N mg/l	PHENOL mg/l	BOD mg/l	TOD mg/l	pH	TON (M)	TSS mg/l	VSS mg/l	PO_4 mg/l	TURB. JTU	TEMP. °F.
1	32.	2.4	1.82	0.170	4.0	50.	7.4	4.00	8.	****	0.10	14.	90.
2	****	4.1	1.50	0.170	7.2	90.	7.6	7.00	15.	****	0.08	17.	90.
3	****	3.7	3.20	0.110	3.2	85.	7.4	****	6.	5.	0.08	18.	89.
4	****	1.9	0.86	0.140	3.6	85.	7.5	****	7.	****	0.06	17.	90.
5	****	1.4	3.20	0.110	20.2	69.	7.7	0.00	6.	****	0.08	16.	90.
6	****	4.1	3.88	0.120	28.8	100.	7.3	****	17.	****	0.10	19.	92.
7	****	6.0	4.16	0.110	23.1	155.	7.5	2.50	27.	****	****	19.	95.
8	****	2.9	3.36	0.140	20.0	75.	7.3	****	11.	****	****	17.	93.
9	****	2.2	4.04	0.120	18.1	40.	7.2	3.00	11.	****	****	17.	95.
10	****	3.1	3.96	0.100	21.7	65.	7.0	****	8.	****	****	12.	95.
11	36.	3.0	3.16	0.120	16.8	50.	7.0	3.00	13.	****	****	9.	93.
12	****	3.5	4.40	0.120	5.0	45.	7.0	****	8.	****	****	9.	94.
13	****	2.2	3.70	0.120	10.0	37.	7.3	2.50	9.	****	0.04	13.	92.
14	****	3.3	4.04	0.120	25.5	105.	7.1	****	14.	****	****	16.	93.
15	****	2.4	3.88	0.120	14.6	68.	7.2	4.00	6.	****	****	12.	92.
16	****	1.7	4.40	0.110	10.8	60.	7.0	****	5.	****	****	11.	93.
17	****	2.2	3.08	0.110	13.1	70.	7.0	3.00	10.	****	****	9.	95.
18	****	1.8	3.44	0.100	8.6	32.	7.0	****	13.	****	****	7.	95.
19	****	5.1	3.56	0.100	7.7	52.	7.2	2.00	17.	****	****	8.	94.
20	****	2.0	3.00	0.120	3.6	59.	7.2	****	7.	****	0.20	11.	95.
21	****	4.4	3.56	0.090	6.4	110.	7.1	2.00	14.	****	****	11.	95.
22	****	2.3	3.24	0.130	8.2	78.	7.0	****	11.	****	****	38.	96.
23	****	1.8	2.60	0.090	2.2	48.	7.0	****	7.	****	****	14.	95.
24	****	2.4	3.20	0.140	5.4	60.	7.0	3.00	11.	9.	****	10.	96.
25	****	2.5	2.70	0.090	7.7	55.	7.3	****	11.	****	****	14.	91.
26	****	2.8	2.84	0.100	11.3	60.	7.4	3.00	12.	****	****	14.	95.
27	32.	1.3	2.50	0.110	4.0	41.	7.3	****	9.	****	0.10	10.	90.
28	****	1.7	4.00	0.130	6.4	33.	7.3	3.00	17.	****	****	11.	93.
29	****	1.7	4.00	0.130	6.4	33.	7.3	****	17.	****	****	****	****
30	****	2.1	3.10	0.110	5.0	28.	7.4	****	11.	****	****	10.	94.
31	****	2.5	1.44	0.100	4.6	25.	7.4	5.00	13.	11.	****	9.	95.
AVERAGE	33.	2.7	3.21	0.117	10.7	62.	7.2	3.13	11.3	8.3	0.09	13.7	93.

APPENDIX C

Table 25: WATER QUALITY DATA SEPTEMBER, 1971 - PROCESS WATER API SEPARATOR EFFLUENT

DATE	FLOW G/D (MM)	OIL		NH$_3$-N mg/l	PHENOL mg/l	BOD mg/l	TOD mg/l	pH	TON (M)	TSS mg/l	VSS mg/l
		I.R. mg/l	APHA mg/l								
1	32.				0.750	47.8	245.	7.4	*****	21.	****
2	****				0.750	30.5	245.	7.4	*****	21.	****
3	31.				0.230	30.5	324.	7.3	*****	32.	****
4	****				0.230	30.5	324.	7.4	*****	32.	****
5	****				1.330	72.8	278.	7.5	*****	50.	****
6	****				1.330	72.8	278.	7.6	*****	50.	****
7	****				0.490	113.3	480.	7.6	*****	53.	31.
8	30.				0.490	113.3	480.	7.6	*****	53.	31.
9	****				1.330	50.4	494.	7.3	*****	52.	****
10	****				1.330	54.4	494.	7.3	*****	52.	****
11	****				*****	71.6	304.	7.6	*****	39.	****
12	****				*****	71.6	304.	7.6	*****	39.	****
13	****				0.190	16.1	161.	7.2	80.00	11.	14.
14	****				0.190	16.1	161.	7.2	80.00	17.	14.
15	30.				0.500	37.8	245.	7.5	*****	30.	****
16	****				0.500	37.8	245.	7.5	*****	30.	****
17	****				0.430	76.6	370.	7.5	*****	29.	****
18	****				0.430	76.6	370.	7.5	*****	29.	****
19	****				0.380	32.2	156.	7.2	*****	14.	****
20	29.				0.380	32.2	156.	7.2	*****	14.	****
21	****				0.550	32.2	179.	7.4	*****	18.	****
22	****				0.550	32.2	179.	7.4	*****	18.	****
23	****				0.150	7.2	117.	7.1	*****	13.	****
24	****				0.150	7.2	117.	7.1	*****	13.	****
25	****				0.610	28.9	190.	7.1	*****	21.	****
26	****				0.610	28.9	190.	7.1	*****	21.	****
27	28.				0.290	7.8	93.	7.3	*****	9.	****
28	****				0.290	7.8	93.	7.3	*****	9.	****
29	****				0.120	5.0	105.	7.1	*****	11.	****
30	****				0.120	5.0	105.	7.1	*****	11.	****
AVERAGE	30.				0.524	41.5	249.	7.3	80.00	27.0	22.5

APPENDIX C

Table 26: WATER QUALITY DATA SEPTEMBER, 1971 - PROCESS WATER BIOPOND EFFLUENT

DATE	FLOW G/D (MM)	OIL I.R. mg/l	OIL APHA mg/l	NH_3-N mg/l	PHENOL mg/l	BOD mg/l	TOD mg/l	pH	TON (M)	TSS mg/l	VSS mg/l	PO_4 mg/l	TURB. JTU
1	32.	39.	17.4	1.92	0.120	12.0	133.	7.5	*****	13.	****	****	43.
2	****	64.	****	1.84	0.210	23.3	230.	8.0	50.00	23.	****	****	49.
3	31.	41.	12.3	1.72	0.190	33.3	102.	7.4	*****	31.	****	0.40	53.
4	****	90.	29.2	2.68	0.100	20.0	273.	7.3	60.00	32.	****	****	44.
5	****	84.	****	1.92	0.120	18.4	93.	7.5	*****	23.	****	****	38.
6	****	84.	****	1.92	0.120	18.4	93.	7.5	*****	23.	****	****	45.
7	****	124.	****	2.36	0.230	30.3	366.	7.4	*****	43.	29.	****	44.
8	30.	94.	46.8	1.24	0.170	29.5	97.	7.5	30.00	33.	****	****	41.
9	****	99.	44.1	5.04	0.270	34.4	250.	7.4	*****	26.	****	****	48.
10	****	102.	44.7	3.24	0.250	35.3	269.	7.3	40.00	26.	****	0.40	122.
11	****	49.	13.0	2.28	0.190	17.5	165.	7.5	*****	24.	****	****	153.
12	****	49.	13.0	2.28	0.190	****	165.	7.5	*****	24.	****	****	124.
13	****	51.	12.8	3.16	0.140	17.8	170.	7.5	40.00	10.	****	****	113.
14	****	48.	15.3	2.68	0.170	24.7	169.	7.3	*****	14.	11.	****	154.
15	30.	52.	15.9	2.92	0.100	21.1	123.	7.4	50.00	****	****	****	150.
16	****	92.	46.5	2.76	0.190	14.7	328.	7.4	*****	25.	****	****	143.
17	****	*****	20.0	2.92	0.190	30.0	150.	7.5	30.00	****	****	0.44	159.
18	****	*****	39.9	3.88	0.110	37.5	275.	7.5	*****	27.	****	****	145.
19	****	49.	****	3.24	0.120	14.7	170.	7.5	17.50	21.	****	****	202.
20	29.	46.	18.7	3.08	0.150	12.0	158.	7.4	*****	****	****	****	113.
21	****	64.	28.8	3.44	0.150	14.7	228.	7.5	17.50	****	9.	****	36.
22	****	66.	19.6	4.80	0.150	26.7	229.	7.3	*****	****	****	****	42.
23	****	73.	****	4.92	0.150	18.3	154.	7.3	12.50	16.	****	****	35.
24	****	66.	25.6	3.08	0.140	27.5	234.	7.1	*****	25.	****	0.32	37.
25	****	52.	****	3.24	0.140	12.0	182.	7.3	15.00	16.	****	****	35.
26	****	52.	****	3.24	0.140	12.0	182.	7.3	15.00	16.	****	****	30.
27	28.	47.	19.9	3.76	0.130	21.1	161.	7.4	*****	15.	****	****	32.
28	****	45.	****	3.08	0.230	32.8	183.	7.2	15.00	15.	1.	****	34.
29	****	42.	12.9	1.84	0.250	23.3	195.	6.8	*****	17.	****	****	36.
30	****	42.	****	2.92	0.120	10.0	136.	6.7	*****	12.	****	****	38.
AVERAGE	30.	64.5	24.8	2.91	0.164	22.1	188.	7.3	30.19	22.0	12.5	0.39	77.9

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Table 27: WATER QUALITY DATA SEPTEMBER, 1971 - PROCESS WATER TERTIARY TREATMENT EFFLUENT

DATE	FLOW G/D (MM)	OIL		NH_3-N mg/l	PHENOL mg/l	BOD mg/l	TOD mg/l	pH	TON (M)	TSS mg/l	VSS mg/l	PO_4 mg/l	TURB. JTU	TEMP. °F.
		I.R. mg/l	APHA mg/l											
1	32.	10.	****	2.00	0.110	4.6	52.	7.5	****	10.	****	****	9.	95.
2	****	19.	5.0	1.84	0.140	9.6	61.	7.3	0.80	15.	****	****	9.	95.
3	31.	15.	3.2	1.72	0.130	10.4	****	7.2	****	10.	****	0.20	9.	94.
4	****	18.	5.1	2.68	0.110	8.2	83.	7.3	3.00	8.	****	****	12.	95.
5	****	12.	3.9	2.00	0.120	12.4	46.	7.3	****	8.	****	****	12.	97.
6	****	12.	3.9	2.00	0.120	12.4	46.	7.3	****	8.	****	****	11.	****
7	****	33.	****	2.16	0.150	7.0	125.	7.3	****	23.	14.	****	15.	95.
8	30.	28.	6.5	1.60	0.120	10.6	****	7.5	4.00	17.	****	****	12.	94.
9	****	39.	12.1	4.64	0.150	23.6	130.	7.3	****	16.	****	****	****	93.
10	****	34.	8.2	3.16	0.130	17.8	85.	7.3	5.00	17.	****	0.24	25.	97.
11	****	20.	6.2	3.16	0.130	10.0	80.	7.3	****	19.	****	****	27.	98.
12	****	20.	****	3.16	0.130	10.0	80.	7.3	****	19.	****	****	22.	97.
13	****	12.	2.9	3.24	0.100	14.5	71.	7.4	4.00	9.	****	****	18.	97.
14	****	13.	2.6	2.60	0.110	16.3	68.	7.2	****	10.	4.	****	15.	97.
15	30.	19.	3.5	2.92	0.120	5.0	62.	7.1	3.00	9.	****	****	18.	94.
16	****	18.	3.4	3.16	0.130	6.4	89.	7.2	****	15.	****	****	16.	94.
17	****	13.	3.1	2.76	0.120	8.2	47.	7.4	2.00	11.	****	0.14	15.	94.
18	****	21.	8.1	3.76	0.110	35.0	185.	7.3	****	20.	****	****	19.	94.
19	****	16.	3.7	3.24	0.100	12.8	60.	7.2	1.75	12.	****	****	20.	93.
20	29.	13.	2.3	3.08	0.110	5.6	46.	7.2	****	5.	****	****	16.	94.
21	****	22.	2.6	2.68	0.130	3.2	72.	7.4	2.00	12.	8.	****	12.	94.
22	****	24.	****	5.04	0.110	5.0	101.	7.3	****	14	****	****	17.	93.
23	****	28.	6.8	4.80	0.090	5.8	66.	7.2	2.50	10.	****	****	18.	93.
24	****	18.	4.1	3.08	0.120	4.6	52.	7.0	****	12.	****	0.20	11.	93.
25	****	34.	2.4	3.24	0.110	3.6	49.	7.2	3.00	6.	****	****	10.	92.
26	****	34.	2.4	3.24	0.110	3.6	49.	7.2	****	6.	****	****	6.	****
27	28.	10.	2.3	3.56	0.110	6.4	60.	7.3	****	6.	****	****	8.	95.
28	****	10.	4.7	2.44	0.430	7.8	59.	7.2	3.00	4.	4.	****	8.	94.
29	****	27.	2.2	3.06	0.310	11.0	75.	7.0	****	10.	****	****	8.	95.
30	****	13.	3.5	3.24	0.290	3.2	50.	6.3	2.00	5.	****	****	10.	97.
AVERAGE	30.	20.3	4.4	2.97	0.141	9.8	73.	7.2	2.77	11.5	7.5	0.19	14.0	94.

APPENDIX C

Table 28: WATER QUALITY DATA OCTOBER, 1971 - PROCESS WATER API SEPARATOR EFFLUENT

DATE	FLOW G/D (MM)	OIL I.R. mg/1	OIL APHA mg/1	NH_3-N mg/1	PHENOL mg/1	BOD mg/1	TOD mg/1	pH	TON (M)	TSS mg/1
1	28.				0.270	22.2	171.	7.2	****	14.
2	****				1.550	74.4	172.	7.7	****	35.
3	****				1.550	74.4	324.	7.7	****	35.
4	****				0.150	24.4	118.	7.4	****	13.
5	30.				0.150	24.4	118.	7.4	****	13.
6	****				4.600	101.1	442.	9.6	****	41.
7	****				4.600	101.0	442.	9.6	****	41.
8	****				4.500	82.2	449.	8.1	****	32.
9	****				4.500	82.2	449.	8.1	****	32.
10	****				0.750	20.0	149.	7.7	****	17.
11	****				0.750	20.0	149.	7.7	****	17.
12	28.				0.190	21.7	146.	7.4	****	13.
13	****				0.190	21.7	146.	7.4	****	13.
14	****				0.360	33.3	102.	7.7	****	18.
15	****				0.360	33.3	102.	7.7	****	18.
16	****				0.880	23.9	****	7.7	****	12.
17	****				0.880	23.9	****	7.7	****	12.
18	29.				0.310	80.0	319.	7.8	****	34.
19	****				0.310	80.0	319.	7.8	****	34.
20	****				0.470	37.2	414.	7.4	****	20.
21	****				0.470	37.2	414.	7.4	****	20.
22	****				0.230	46.1	233.	7.2	****	26.
23	****				0.230	46.1	233.	7.2	****	26.
24	****				0.230	46.1	****	***	****	26.
25	****				1.120	104.4	271.	7.5	****	34.
26	****				1.120	104.4	271.	7.5	****	34.
27	****				0.680	47.8	****	7.4	****	21.
28	31.				0.680	47.8	****	7.4	****	21.
29	****				0.640	56.7	332.	7.6	****	25.
30	****				0.640	56.7	332.	7.6	****	25.
31	****				0.640	56.7	****	7.6	****	25.
AVERAGE	29.				1.096	52.6	264.	7.7		24.0

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Table 29: WATER QUALITY DATA OCTOBER, 1971 - PROCESS WATER BIOPOND EFFLUENT

DATE	FLOW G/D (MM)	OIL I.R. mg/l	OIL APHA mg/l	NH_3-N mg/l	PHENOL mg/l	BOD mg/l	TOD mg/l	pH	TON (M)	TSS mg/l	VSS mg/l	PO_4 mg/l	TURB. JTU
1	28.	39.	19.4	3.56	0.110	10.8	123.	7.3	15.00	9.	****	0.34	31.
2	****	*****	18.9	3.08	0.230	13.9	132.	7.6	1.75	11.	****	****	31.
3	****	*****	18.9	3.08	0.230	13.9	132.	7.6	1.75	11.	****	****	31.
4	****	*****	20.6	2.60	0.130	27.2	172.	7.5	******	16.	****	****	34.
5	30.	*****	21.7	3.56	0.210	20.0	122.	7.5	6.00	13.	10.	****	38.
6	****	65.	23.0	3.16	0.170	18.1	147.	7.5	******	17.	****	****	38.
7	****	98.	62.3	4.28	0.140	41.1	294.	7.5	12.50	29.	****	****	37.
8	****	47.	22.5	5.16	*****	32.0	79.	8.1	******	27.	****	****	42.
9	****	101.	46.8	5.04	0.150	31.1	279.	7.6	17.50	25.	****	****	42.
10	****	68.	22.5	3.88	0.170	18.9	202.	7.8	******	19.	****	****	46.
11	****	122.	23.9	6.16	0.150	25.3	200.	***	******	20.	****	****	47.
12	28.	56.	17.8	4.28	0.140	17.5	207.	7.5	25.00	17.	14.	****	59.
13	****	*****	23.4	6.16	0.150	27.5	210.	7.6	******	21.	****	****	59.
14	****	116.	60.1	4.80	0.290	55.9	326.	7.5	40.00	27.	****	****	70.
15	****	70.	30.3	4.92	0.150	28.9	227.	7.5	******	27.	****	0.22	60.
16	****	*****	51.4	5.16	0.230	32.5	162.	7.8	20.00	28.	****	****	40.
17	****	40.	14.1	4.28	0.170	10.3	106.	7.7	******	23.	****	****	41.
18	29.	111.	63.6	3.88	0.190	24.7	380.	7.7	30.00	34.	****	****	43.
19	****	96.	39.6	6.40	0.230	71.2	362.	7.7	******	22.	19.	****	38.
20	****	98.	45.6	6.40	0.190	41.4	283.	***	25.00	25.	****	****	52.
21	****	87.	38.4	5.32	0.140	22.0	294.	7.4	******	21.	****	****	44.
22	****	78.	43.2	7.28	0.210	59.2	333.	7.1	500.00	25.	****	0.22	46.
23	****	*****	13.8	5.68	0.090	26.1	143.	7.0	100.00	13.	****	****	47.
24	****	*****	13.8	5.68	0.090	26.1	143.	***	******	13.	****	****	46.
25	****	*****	18.4	7.76	0.210	11.4	198.	7.4	******	15.	****	****	42.
26	****	147.	83.8	6.00	0.360	47.2	231.	7.4	50.00	35.	24.	****	52.
27	****	99.	53.6	5.68	0.270	28.9	135.	7.5	******	38.	****	****	42.
28	31.	68.	31.7	5.68	0.250	48.9	48.	7.2	50.00	20.	****	****	46.
29	****	*****	32.6	5.48	0.410	37.5	168.	7.4	******	25.	****	****	35.
30	****	74.	27.8	5.04	0.430	38.1	264.	7.6	125.00	13.	****	0.34	40.
31	****	74.	27.8	5.04	0.430	38.1	264.	7.6	******	13.	****	****	66.
AVERAGE	29.	83.5	33.2	4.98	0.210	30.5	205.	7.5	63.71	21.0	16.7	0.28	44.7

APPENDIX C

Table 30: WATER QUALITY DATA OCTOBER, 1971 - PROCESS WATER TERTIARY TREATMENT EFFLUENT

DATE	FLOW G/D (MM)	OIL		NH_3-N mg/l	PHENOL mg/l	BOD mg/l	TOD mg/l	pH	TON (M)	TSS mg/l	VSS mg/l	PO_4 mg/l	TURB. JTU	TEMP. °F.
		I.F. mg/l	APHA mg/l											
1	28.	11.	1.3	2.84	0.090	2.4	49.	7.3	1.25	4.	****	0.10	5.	90.
2	****	****	2.1	3.00	0.100	1.8	44.	7.5	8.00	5.	****	****	7.	96.
3	****	****	2.1	3.00	0.100	1.8	44.	7.5	8.00	5.	****	****	5.	****
4	****	****	3.1	2.76	0.100	5.0	65.	7.4	*****	6.	****	****	7.	91.
5	30.	****	4.4	3.08	0.110	7.4	46.	7.4	1.75	5.	4.	****	9.	92.
6	****	18.	2.5	3.16	0.110	2.8	41.	7.4	*****	5.	****	****	9.	92.
7	****	22.	5.9	3.96	0.140	4.2	60.	7.3	4.00	10.	****	****	11.	89.
8	****	****	2.2	4.40	0.120	11.8	45.	7.6	*****	8.	****	****	11.	88.
9	****	21.	****	4.92	0.130	2.7	68.	7.5	1.00	10.	****	****	11.	88.
10	****	21.	****	3.88	0.140	1.9	59.	7.6	*****	6.	****	****	9.	87.
11	****	20.	4.9	6.00	0.110	5.2	72.	7.5	*****	6.	****	****	14.	86.
12	28.	13.	2.5	3.16	0.090	6.8	77.	7.3	2.00	7.	7.	****	9.	87.
13	****	13.	3.0	6.16	0.100	5.6	57.	7.5	*****	6.	****	****	10.	89.
14	****	19.	****	3.76	0.170	5.0	78.	7.5	5.00	14.	****	****	10.	88.
15	****	15.	8.8	4.80	0.090	3.6	83.	7.5	*****	8.	****	0.06	10.	88.
16	****	26.	7.6	5.16	0.080	5.0	37.	7.6	9.00	13.	****	****	8.	91.
17	****	11.	2.6	4.52	0.140	3.6	28.	7.6	*****	8.	****	****	7.	91.
18	29.	21.	4.9	3.08	0.110	6.8	60.	7.6	10.00	10.	****	****	7.	92.
19	****	28.	6.7	5.64	*****	28.5	103.	7.6	*****	17.	15.	****	8.	90.
20	****	18.	4.2	5.64	0.100	6.8	45.	7.6	8.00	9.	****	****	13.	92.
21	****	20.	3.1	5.16	0.140	1.3	48.	7.3	*****	6.	****	****	6	92.
22	****	18.	4.4	6.60	0.110	10.4	75.	7.2	6.00	12.	****	0.02	9.	92.
23	****	11.	3.9	6.48	0.130	****	****	6.8	10.00	18.	****	****	10.	89.
24	****	11.	3.9	6.48	0.130	****	****	***	10.00	18.	****	****	15.	****
25	****	****	3.4	6.88	0.130	9.3	71.	7.2	*****	8.	****	****	8.	88.
26	****	****	8.1	6.88	0.170	7.4	58.	7.3	10.00	15.	15.	****	6.	91.
27	****	****	6.6	6.72	0.130	5.4	28.	7.3	*****	11.	****	****	9.	92.
28	31.	18.	6.7	7.12	0.170	4.3	48.	***	12.50	11.	****	****	6.	91.
29	****	18.	5.3	5.80	0.230	15.6	45.	7.5	*****	15.	****	****	8.	92.
30	****	24.	****	4.64	0.250	20.0	68.	7.5	10.00	9.	****	0.10	9.	91.
31	****	24.	****	4.64	0.250	20.0	68.	7.5	*****	9.	****	****	11.	****
AVERAGE	29.	18.3	4.3	4.84	0.132	7.3	57.	7.4	6.85	9.4	10.2	0.07	8.9	90.

APPENDIX C

Table 31: WATER QUALITY DATA NOVEMBER, 1971 - API SEPARATOR EFFLUENT

DATE	FLOW G/D (MM)	OIL I.R. mg/l	OIL APHA mg/l	NH_3-N mg/l	PHENOL mg/l	BOD mg/l	TOD mg/l	pH	TON (M)	TSS mg/l	VSS mg/l	PO_4 mg/l	TURB. JTU
1	31				0.880	22.8	81.	7.3	****	11.	****	****	31.
2	****				0.880	22.8	****	7.3	****	11.	****	****	22.
3	****				2.500	63.3	476.	7.4	****	37.	****	****	20.
4	****				2.500	63.3	476.	7.4	****	37.	****	****	28.
5	****				4.000	19.4	199.	8.0	****	18.	****	****	33.
6	****				4.000	19.4	199.	8.0	****	18.	****	****	23.
7	****				5.640	77.2	203.	8.7	****	17.	****	****	27.
8	31.				5.640	77.2	304.	8.7	****	17.	****	****	34.
9	****				0.250	47.2	304.	8.6	****	24.	****	****	36.
10	****				3.460	47.2	****	8.6	****	24.	****	****	29.
11	****				0.230	26.7	127.	7.8	****	22.	****	****	33.
12	****				0.230	26.7	127.	7.8	****	22.	****	****	25.
13	****				0.380	28.3	142.	7.4	****	26.	****	****	24.
14	****				0.380	28.3	142.	7.4	****	26.	****	****	27.
15	****				0.170	19.4	79.	7.4	****	11.	****	****	27.
16	****				0.170	19.4	79.	7.4	****	11.	****	****	27.
17	33.				0.590	23.9	648.	7.7	****	45.	****	****	21.
18	****				0.590	23.9	648.	7.7	****	45.	****	****	20.
19	****				0.250	46.1	358.	7.1	****	123.	****	****	18.
20	****				0.250	46.1	358.	7.1	****	123.	****	****	17.
21	****				*****	****	****	***	****	*****	****	****	21.
22	****				*****	****	****	***	****	*****	****	****	****
23	****				*****	****	****	***	****	*****	****	****	32.
24	****				*****	****	****	***	****	*****	****	****	29.
25	****				*****	****	****	***	****	*****	****	****	21.
26	****				*****	****	****	***	****	*****	****	****	27.
27	****				*****	****	****	***	****	*****	****	****	27.
28	****				*****	****	****	***	****	*****	****	****	29.
29	32.				*****	****	****	***	****	*****	****	****	28.
30	****				*****	****	****	***	****	*****	****	****	26.
AVERAGE	31.				1.649	37.4	275.	7.7		33.4			26.2

APPENDIX C

Table 32: WATER QUALITY DATA NOVEMBER, 1971 - PROCESS WATER BIOPOND EFFLUENT

DATE	FLOW G/D (MM)	OIL		NH$_3$-N mg/l	PHENOL mg/l	BOD mg/l	TOD mg/l	pH	TON (M)	TSS mg/l	VSS mg/l	PO$_4$ mg/l	TURB. JTU
		I.R. mg/l	APHA mg/l										
1	31.	44.	14.5	4.04	0.170	30.3	133.	7.6	*****	9.	****	****	84.
2	****	44.	11.3	3.44	*****	39.7	136.	7.6	70.00	12.	11.	****	63.
3	****	44.	****	3.96	0.150	41.1	125.	7.5	*****	16.	****	****	44.
4	****	*****	36.4	3.96	0.170	22.5	156.	7.4	40.00	18.	****	****	41.
5	****	47.	17.4	4.40	0.150	26.9	114.	7.3	*****	20.	****	****	44.
6	****	70.	31.4	5.32	0.190	25.8	144.	7.5	20.00	22.	****	0.38	33.
7	****	36.	11.1	3.08	0.150	28.1	153.	7.3	*****	15.	****	****	31.
8	31.	48.	19.2	5.48	0.290	21.4	226.	8.0	*****	28.	****	****	40.
9	****	*****	21.3	7.40	0.310	30.9	394.	8.3	50.00	21.	15.	****	47.
10	****	39.	11.8	7.40	0.270	32.5	237.	8.2	*****	13.	****	****	49.
11	****	87.	42.7	8.20	0.290	35.3	168.	7.5	20.00	27.	****	****	34.
12	****	43.	11.4	6.60	0.180	20.0	95.	7.7	*****	15.	****	****	43.
13	****	68.	28.9	6.84	0.250	29.2	95.	7.6	15.00	22.	****	0.30	32.
14	****	33.	9.1	6.16	0.270	21.7	74.	7.5	*****	20.	****	****	36.
15	****	30.	11.9	7.72	0.390	29.4	93.	7.5	12.50	19.	****	****	40.
16	****	84.	****	7.52	0.230	19.7	107.	7.3	*****	20.	11.	****	40.
17	33.	*****	17.5	9.04	0.190	27.5	175.	7.4	15.00	14.	****	****	45.
18	****	101.	41.7	8.56	0.290	57.2	141.	7.7	*****	23.	****	****	39.
19	****	*****	35.6	8.56	0.230	46.1	157.	7.5	12.50	27.	****	****	36.
20	****	91.	47.6	9.40	0.190	53.4	185.	7.2	*****	20.	****	0.30	30.
21	****	44.	17.4	7.90	0.170	28.3	144.	7.5	15.00	11.	****	****	24.
22	****	38.	16.8	2.90	0.170	23.9	151.	7.7	*****	20.	****	****	23.
23	****	39.	12.9	7.10	0.250	29.7	127.	7.7	25.00	18.	15.	****	29.
24	****	*****	25.4	7.56	0.380	28.9	136.	7.7	*****	36.	****	0.32	27.
25	****	*****	25.4	7.56	0.380	28.9	136.	7.6	*****	36.	****	****	28.
26	****	*****	13.9	9.40	0.230	16.6	92.	7.6	10.00	19.	****	****	33.
27	****	73.	30.8	10.40	0.270	29.2	134.	7.9	*****	27.	****	****	30.
28	****	31.	12.1	9.40	0.210	16.9	75.	7.8	17.50	24.	****	****	31.
29	32.	46.	15.8	6.30	0.270	20.0	143.	7.8	*****	26.	****	****	33.
30	****	*****	22.6	9.28	0.290	31.1	174.	7.7	15.00	21.	10.	0.28	32.
AVERAGE	31.	53.6	21.9	6.82	0.240	29.7	147.	7.6	24.10	20.6	12.4	0.31	38.0

APPENDIX C

Table 33: WATER QUALITY DATA NOVEMBER, 1971 -- PROCESS WATER TERTIARY TREATMENT EFFLUENT

DATE	FLOW G/D (MM)	OIL		NH$_3$-N mg/l	PHENOL mg/l	BOD mg/l	TOD mg/l	pH	TON (M)	TSS mg/l	VSS mg/l	PO$_4$ mg/l	TURB. JTU	TEMP. °F.
		I.R. mg/l	APHA mg/l											
1	31.	14.	3.8	4.40	0.110	17.8	36.	7.4	*****	7.	****	****	16.	88.
2	****	13.	1.8	3.24	0.130	14.5	21.	7.3	10.00	6.	6.	****	9.	85.
3	****	14.	1.6	4.28	0.120	11.1	32.	7.4	*****	7.	****	****	7.	85.
4	****	22.	****	4.52	0.140	13.6	71.	7.3	2.00	10.	****	****	5.	82.
5	****	****	1.6	4.28	0.110	8.6	64.	7.0	*****	7.	****	****	5.	81.
6	****	****	4.4	4.92	0.140	7.4	34.	7.6	2.50	10.	****	0.00	4.	83.
7	****	10.	1.8	3.44	0.100	3.6	55.	7.2	*****	6.	****	****	5.	78.
8	31.	21.	1.9	5.16	0.250	4.7	40.	7.9	*****	8.	****	****	6.	81.
9	****	15.	5.0	7.40	0.170	8.3	105.	7.7	10.00	9.	****	****	8.	80.
10	****	15.	4.6	7.72	0.150	5.8	71.	8.1	*****	14.	****	****	14.	79.
11	****	25.	6.3	7.06	0.130	8.6	64.	7.3	1.50	15.	****	****	5.	79.
12	****	18.	2.6	6.40	0.140	1.9	18.	7.7	*****	6.	****	****	8.	80.
13	****	23.	6.4	6.40	0.190	8.6	41.	7.4	2.50	15.	****	0.00	8.	81.
14	****	****	1.5	5.64	0.170	6.0	18.	7.3	*****	7.	****	****	8.	80.
15	****	15.	2.5	5.80	0.340	7.5	23.	7.5	1.25	8.	****	****	9.	82.
16	****	17.	4.7	7.50	0.140	5.6	41.	7.1	*****	12.	8.	****	9.	82.
17	33.	****	3.2	8.80	0.150	6.0	53.	7.1	1.75	7.	****	****	15.	84.
18	****	17.	4.9	7.92	0.140	10.4	49.	7.2	*****	13.	****	****	8.	85.
19	****	26.	5.7	8.56	0.140	****	79.	7.3	6.00	13.	****	****	10.	83.
20	****	24.	****	4.30	0.130	****	69.	7.0	*****	18.	****	0.00	11.	82.
21	****	16.	****	9.40	0.140	17.0	51.	7.1	7.00	9.	****	****	5.	79.
22	****	15.	2.9	3.00	0.110	12.4	59.	7.5	*****	7.	****	****	5.	79.
23	****	****	2.8	7.90	0.210	14.6	52.	7.4	6.00	18.	14.	****	7.	****
24	****	30.	****	8.20	0.230	16.4	74.	7.5	*****	20.	****	0.00	7.	80.
25	****	30.	****	8.20	0.230	16.4	74.	7.5	*****	20.	****	****	17.	****
26	****	17.	6.7	8.60	0.230	6.7	49.	7.5	2.00	8.	****	****	7.	****
27	****	18.	5.4	8.60	0.150	13.1	56.	7.7	*****	14.	****	****	8.	79.
28	****	19.	3.9	10.40	0.130	5.4	44.	7.7	2.50	10.	****	****	9.	79.
29	32.	****	1.1	*****	0.210	9.5	49.	7.7	*****	13.	****	****	12.	78.
30	****	20.	4.4	5.80	0.230	6.8	54.	7.6	1.75	11.	8.	0.00	13.	77.
AVERAGE	31.	18.9	3.6	6.47	0.165	9.5	51.	7.4	4.05	10.9	9.0	0.00	8.6	81.

APPENDIX C

Table 34: WATER QUALITY DATA DECEMBER, 1971 - PROCESS WATER API SEPARATOR EFFLUENT

DATE	FLOW G/D (MM)	OIL		NH_3-N mg/l	PHENOL mg/l	BOD mg/l	TOD mg/l	pH	TON (M)	TSS mg/l	VSS mg/l	PO_4 mg/l	TURB. JTU
		I.R. mg/l	APHA mg/l										
1	32.				1.160	120.0	494.	7.5	****	65.	****	****	31.
2	****				1.160	120.0	494.	7.5	****	65.	****	****	23.
3	****				2.200	274.4	*****	7.5	****	90.	****	****	32.
4	****				2.200	274.4	*****	7.5	****	90.	****	****	29.
5	****				*****	*****	*****	***	****	****	****	****	26.
6	****				*****	*****	*****	***	****	****	****	****	25.
7	29.				*****	*****	*****	***	****	****	****	****	****
8	****				*****	*****	*****	***	****	****	****	****	24.
9	****				*****	*****	*****	***	****	****	****	****	24.
10	****				*****	*****	*****	***	****	****	****	****	36.
11	****				7.550	47.2	299.	7.9	****	33.	****	****	30.
12	****				7.550	47.2	299.	7.9	****	33.	****	****	27.
13	****				5.950	152.2	550.	8.0	****	86.	35.	****	32.
14	****				5.950	152.2	550.	8.0	****	86.	35.	****	27.
15	****				3.760	82.2	666.	8.3	****	59.	****	****	25.
16	****				3.760	82.2	666.	8.3	****	59.	****	****	24.
17	****				4.600	45.5	*****	7.9	****	55.	****	****	24.
18	****				4.600	45.5	*****	7.9	****	55.	****	****	25.
19	****				1.330	37.8	178.	7.5	****	23.	****	****	46.
20	****				1.330	37.8	178.	7.5	****	23.	****	****	50.
21	****				2.180	75.0	240.	7.6	****	24.	****	****	39.
22	****				2.180	75.0	240.	7.6	****	24.	****	****	42.
23	****				1.120	72.2	*****	7.3	****	46.	****	****	37.
24	****				1.120	72.2	*****	7.3	****	46.	****	****	36.
25	****				0.590	27.8	270.	7.5	****	35.	****	****	33.
26	****				0.590	27.8	270.	7.5	****	35.	****	****	26.
27	****				2.260	96.6	*****	7.5	****	72.	****	****	27.
28	****				2.260	96.6	460.	7.5	****	72.	****	****	31.
29	****				2.430	83.9	460.	7.8	****	51.	****	****	34.
30	****				2.430	83.9	*****	7.8	****	51.	****	****	37.
31	****				1.330	342.7	1136.	7.5	****	31.	****	****	49.
AVERAGE	30.				2.863	102.8	438.	7.6	0.00	52.3	35.0	0.00	31.7

APPENDIX C

Table 35: WATER QUALITY DATA DECEMBER, 1971 - PROCESS WATER BIOPOND EFFLUENT

DATE	FLOW G/D (MM)	OIL		NH_3-N mg/l	PHENOL mg/l	BOD mg/l	TOD mg/l	pH	TON (M)	TSS mg/l	VSS mg/l	PO_4 mg/l	TURB. JTU
		I.R. mg/l	APHA mg/l										
1	32.	82.	39.3	2.80	0.310	30.0	190.	7.7	*****	33.	****	****	33.
2	****	79.	41.9	5.40	0.210	38.9	206.	7.6	17.50	43.	****	****	41.
3	****	53.	****	9.40	0.250	52.2	201.	7.3	*****	21.	****	****	41.
4	****	71.	30.4	6.70	0.210	63.9	221.	7.3	15.00	33.	****	****	38.
5	****	90.	23.7	4.30	0.310	39.5	235.	7.5	*****	31.	****	****	36.
6	****	49.	20.2	1.20	0.190	21.1	208.	7.4	17.50	18.	****	0.16	45.
7	29.	61.	20.8	****	0.190	35.6	206.	7.5	*****	22.	20.	****	****
8	****	65.	26.5	7.72	0.230	40.0	212.	7.5	12.50	17.	****	****	58.
9	****	129.	52.0	5.40	0.210	49.2	352.	7.4	*****	33.	****	****	58.
10	****	*****	20.4	5.64	0.950	75.9	345.	7.4	12.50	17.	****	****	66.
11	****	93.	****	6.00	0.270	67.3	435.	7.5	17.50	29.	****	****	146.
12	****	46.	****	8.08	0.530	24.7	240.	7.7	*****	19.	****	0.36	104.
13	****	*****	14.7	5.84	1.060	47.8	259.	7.5	30.00	17.	****	****	81.
14	****	155.	90.0	17.70	2.440	122.5	510.	7.6	*****	56.	27.	****	87.
15	****	114.	49.3	14.50	3.360	75.9	330.	7.6	17.50	22.	****	****	153.
16	****	124.	53.9	14.50	3.020	71.4	316.	7.6	*****	26.	****	****	151.
17	****	114.	45.8	19.30	3.760	68.4	198.	7.5	20.00	19.	****	****	151.
18	****	54.	23.1	3.60	2.260	40.0	120.	7.9	12.50	18.	****	0.54	195.
19	****	54.	23.1	3.60	2.260	40.0	129.	7.9	12.50	18.	****	****	111.
20	****	*****	12.2	3.80	0.190	31.7	123.	7.8	*****	15.	****	****	48.
21	****	59.	16.6	4.52	0.430	26.4	153.	7.8	12.50	20.	15.	****	45.
22	****	84.	24.7	7.12	0.750	40.0	186.	7.5	*****	21.	****	****	87.
23	****	64.	18.5	7.50	0.470	27.2	214.	7.2	*****	28.	****	****	101.
24	****	64.	18.5	7.50	0.470	27.2	214.	7.2	*****	28.	****	****	94.
25	****	45.	20.6	9.70	0.250	38.4	232.	7.2	15.00	26.	****	****	78.
26	****	45.	20.6	9.70	0.250	38.4	232.	7.2	15.00	26.	****	0.44	54.
27	****	73.	22.5	4.30	0.310	43.6	206.	7.3	*****	31.	****	****	56.
28	****	112.	47.8	4.00	0.210	76.7	397.	7.3	25.00	42.	15.	****	52.
29	****	73.	27.7	4.80	0.360	52.8	219.	7.6	*****	18.	****	****	58.
30	****	67.	****	5.80	0.380	49.2	173.	7.7	15.00	30.	****	****	128.
31	****	105.	38.9	6.16	0.270	49.8	281.	7.5	*****	34.	****	0.39	62.
AVERAGE	30.	79.4	31.2	7.21	0.850	48.5	243.	7.5	16.71	26.1	19.2	0.37	81.9

APPENDIX C

Table 36: WATER QUALITY DATA DECEMBER, 1971 - PROCESS WATER TERTIARY TREATMENT EFFLUENT

		OIL												
DATE	FLOW G/D MM	I.R. mg/1	APHA mg/1	NH_3-N mg/1	PHENOL mg/1	BOD mg/1	TOD mg/1	pH	TON (M)	TSS mg/1	VSS mg/1	PO_4 mg/1	TURB. JTU	TEMP. °F
1	32.	22.	7.3	5.00	0.170	6.4	50.	7.5	*****	13.	****	****	13.	77.
2	***	17.	5.2	2.50	0.190	13.2	58.	7.4	17.50	14.	****	****	13.	78.
3	***	18.	2.8	8.90	0.150	36.9	88.	7.2	*****	19.	****	****	12.	80.
4	***	17.	5.6	5.50	0.150	41.0	108.	7.3	12.50	13.	****	****	11.	77.
5	***	14.	2.8	2.30	0.250	13.6	71.	7.4	*****	36.	****	****	10.	78.
6	***	44.	9.0	1.24	0.150	11.8	164.	7.4	12.50	32.	****	0.00	17.	80.
7	29.	18.	2.9	3.36	0.140	13.1	132.	7.5	*****	32.	14.	****	***	78.
8	***	15.	2.4	5.64	0.170	8.2	60.	7.4	12.50	8.	****	****	15.	79.
9	***	37.	6.9	5.00	0.170	14.5	114.	7.3	*****	18.	****	****	20.	78.
10	***	24.	5.4	5.16	1.220	44.9	150.	7.4	10.00	11.	****	****	17.	79.
11	***	21.	3.7	4.64	0.130	25.3	130.	7.5	8.00	17.	****	****	11.	78.
12	***	12.	2.3	7.08	0.210	10.4	55.	7.6	*****	5.	****	0.00	11.	79.
13	***	22.	2.9	4.72	0.850	23.8	132.	7.4	8.00	7.	****	****	15.	78.
14	***	40.	12.0	20.50	2.860	52.7	127.	7.4	*****	21.	16.	****	21.	76.
15	***	36.	10.2	15.40	3.020	33.6	198.	7.4	17.50	19.	****	****	32.	77.
16	***	***	11.3	15.40	3.100	29.5	172.	7.4	*****	15.	****	****	22.	77.
17	***	40.	12.9	18.50	3.200	37.2	121.	7.5	10.00	20.	****	****	22.	75.
18	***	13.	4.3	4.10	1.730	20.8	****	7.9	7.00	6.	****	0.00	41.	73.
19	***	13.	4.3	4.10	1.730	20.8	****	7.9	7.00	6.	****	0.00	14.	***
20	***	***	1.5	3.70	0.210	19.6	78.	7.5	*****	5.	****	****	6.	76.
21	***	10.	1.8	4.80	0.310	15.8	43.	7.8	7.00	6.	6.	****	6.	75.
22	***	16.	1.7	7.92	0.900	20.8	82.	7.4	*****	6.	****	****	15.	72.
23	***	13.	7.3	8.60	0.210	8.8	78.	7.1	*****	7.	****	****	10.	72.
24	***	13.	7.3	8.60	0.210	8.8	78.	7.1	*****	7.	****	****	9.	***
25	***	8.	1.9	6.50	0.250	6.8	73.	7.1	9.00	14.	****	****	7.	75.
26	***	8.	1.9	6.50	0.250	6.8	73.	7.1	9.00	14.	****	0.15	13.	***
27	***	***	2.9	*****	0.270	15.0	116.	7.2	*****	15.	****	****	10.	75.
28	***	34.	8.6	*****	0.210	36.4	137.	7.2	25.00	9.	****	****	13.	73.
29	***	17.	3.4	4.16	0.310	26.8	134.	7.5	*****	9.	****	****	9.	75.
30	***	13.	2.7	5.64	0.380	13.8	69.	7.8	10.00	8.	****	****	13.	75.
31	***	15.	4.3	5.64	0.470	12.2	83.	7.5	*****	13.	****	0.05	7.	74.
AVERAGE	30.	20.3	5.1	6.93	0.760	20.9	102.	7.4	11.40	13.7	12.0	0.04	14.5	76.

APPENDIX C

Table 37: **WATER QUALITY DATA JANUARY, 1972 - PROCESS WATER API SEPARATOR EFFLUENT**

DATE	FLOW G/D (MM)	OIL		NH$_3$-N mg/l	PHENOLS mg/l	BOD mg/l	TOD mg/l	pH	TON (M)	TSS mg/l	VSS mg/l	PO$_4$ mg/l	TURB. JTU
		I.R. mg/l	APHA mg/l										
1	29.				1.330	342.7	1136.	7.7	****	31.	****	****	42.
2	****				3.460	97.2	1136.	7.6	****	26.	****	****	43.
3	27.				3.460	97.2	208.	7.6	****	26.	****	****	51.
4	****				2.560	206.6	208.	***	****	35.	****	****	57.
5	****				2.560	206.6	754.	7.7	****	35.	****	****	60.
6	****				5.200	149.9	754.	8.3	****	73.	****	****	59.
7	****				5.200	149.9	754.	8.3	****	73.	****	****	60.
8	****				2.300	52.2	201.	7.6	****	26.	****	****	51.
9	****				2.300	52.2	201.	7.6	****	20.	****	****	58.
10	28.				1.090	265.5	940.	7.0	****	129.	****	****	51.
11	****				1.090	265.5	940.	7.0	****	129.	****	****	52.
12	****				2.860	374.5	926.	7.4	****	77.	60.	****	51.
13	****				2.860	374.5	926.	7.4	****	77.	60.	****	52.
14	****				3.860	224.9	446.	7.9	****	52.	****	****	52.
15	****				3.860	224.9	446.	7.9	****	52.	****	****	75.
16	****				6.650	73.3	183.	7.5	****	7.	****	****	75.
17	29.				6.650	73.3	183.	7.5	****	7.	****	****	62.
18	****				2.600	403.4	608.	7.6	****	82.	****	****	57.
19	****				2.600	403.4	608.	7.6	****	82.	****	****	54.
20	****				2.260	106.7	460.	7.5	****	61.	****	****	57.
21	****				2.260	106.7	460.	7.5	****	61.	****	****	60.
22	****				0.540	21.7	145.	7.6	****	13.	****	****	60.
23	****				0.540	21.7	145.	7.6	****	13.	****	****	57.
24	31.				4.250	72.2	375.	7.7	****	13.	****	****	62.
25	****				4.250	72.2	375.	7.7	****	13.	****	****	57.
26	****				3.680	712.3	1096.	7.1	****	141.	****	****	69.
27	****				3.680	712.3	1096.	7.1	****	141.	****	****	53.
28	****				4.400	207.1	594.	7.2	****	28.	****	****	62.
29	****				4.400	207.1	594.	7.2	****	28.	****	****	48.
30	****				7.500	119.4	*****	7.2	****	13.	****	****	43.
31	****				*****	*****	*****	***	****	*****	****	****	64.
AVERAGE	28.				3.341	213.2	582.	7.5	0.00	52.1	60.0	0.00	56.5

APPENDIX C

Table 38: WATER QUALITY DATA JANUARY, 1972 - PROCESS WATER BIOPOND EFFLUENT

DATE	FLOW G/D (MM)	OIL		NH_3-N mg/l	PHENOL mg/l	BOD mg/l	TOD mg/l	pH	TON (M)	TSS mg/l	VSS mg/l	PO_4 mg/l	TURB. JTU
		I.R. mg/l	APHA mg/l										
1	29.	105.	38.9	6.16	0.270	49.8	281.	7.5	*****	34.	****	****	48.
2	****	40.	15.9	6.16	0.250	36.7	139.	7.5	20.00	28.	****	****	51.
3	27.	48.	21.7	7.40	0.380	30.0	157.	7.5	*****	20.	****	****	55.
4	****	210.	99.9	6.00	0.380	86.7	309.	7.4	30.00	30.	20.	0.72	57.
5	****	107.	54.3	5.48	0.380	42.8	363.	7.5	*****	43.	****	****	68.
6	****	94.	37.4	6.16	0.430	91.4	311.	7.7	*****	42.	****	****	69.
7	****	115.	52.2	7.76	0.390	104.2	460.	7.7	40.00	62.	****	****	68.
8	****	50.	14.3	6.60	0.170	29.7	157.	7.7	*****	17.	****	****	72.
9	****	50.	14.3	6.60	0.170	29.7	157.	7.7	*****	17.	****	0.76	59.
10	28.	25.	9.2	5.04	0.290	27.2	158.	7.5	25.00	22.	****	****	55.
11	****	192.	69.9	4.40	0.380	95.6	466.	7.0	*****	70.	23.	****	50.
12	****	119.	50.5	5.80	0.360	82.5	386.	7.1	25.00	20.	****	****	68.
13	****	120.	44.4	6.16	0.340	65.3	377.	7.3	*****	35.	****	****	64.
14	****	80.	25.9	8.80	0.250	72.3	319.	7.1	30.00	34.	****	****	66.
15	****	57.	34.6	6.00	0.390	65.9	263.	7.5	*****	25.	****	****	67.
16	****	57.	34.6	6.00	0.390	65.9	263.	7.5	*****	25.	****	0.52	70.
17	29.	47.	12.5	5.80	0.310	36.7	169.	7.4	30.00	21.	****	****	69.
18	****	129.	54.6	3.24	0.500	67.0	324.	7.4	*****	41.	30.	****	58.
19	****	82.	35.4	1.28	0.390	36.7	183.	7.6	25.00	24.	****	****	51.
20	****	93.	40.2	1.62	0.360	55.9	274.	7.9	*****	29.	****	****	54.
21	****	107.	40.2	3.16	0.380	67.0	266.	7.3	40.00	41.	****	****	46.
22	****	40.	****	2.02	0.250	15.3	155.	7.6	*****	21.	****	0.59	53.
23	****	40.	****	2.02	0.250	15.3	155.	7.6	*****	21.	****	****	49.
24	31.	150.	75.0	2.26	0.450	60.6	440.	7.8	40.00	21.	****	****	64.
25	****	85.	25.7	1.78	0.490	61.7	347.	7.7	*****	28.	18.	****	220.
26	****	48.	14.6	1.82	0.750	63.4	258.	7.5	30.00	28.	****	****	63.
27	****	96.	50.6	1.54	0.530	55.6	287.	7.1	25.00	38.	****	0.48	83.
28	****	47.	50.6	1.54	0.380	31.7	192.	7.2	*****	28.	****	****	58.
29	****	83.	35.8	1.46	0.310	71.4	352.	7.2	30.00	20.	****	****	74.
30	****	34.	10.2	1.50	0.530	37.2	233.	7.2	*****	13.	****	0.44	59.
31	****	43.	8.6	1.54	0.640	31.3	252.	7.1	12.50	18.	****	****	41.
AVERAGE	28.	83.6	35.7	4.29	0.378	54.2	272.	7.4	28.75	29.5	22.7	0.58	65.4

APPENDIX C

Table 39: WATER QUALITY DATA JANUARY, 1971 - PROCESS WATER TERTIARY TREATMENT EFFLUENT

DATE	FLOW G/D MM	OIL		NH_3-N mg/1	PHENOL mg/1	BOD mg/1	TOD mg/1	pH	TON (M)	TSS mg/1	VSS mg/1	PO_4 mg/1	TURB. JTU	TEMP. °F
		I.R. mg/1	APHA mg/1											
1	29.	15.	4.3	5.64	0.470	12.2	33.	7.5	*****	13.	****	****	6.	***
2	***	7.	3.4	7.40	0.360	26.4	43.	7.3	10.00	7.	****	****	6.	76.
3	27.	11.	2.0	7.40	0.290	14.5	52.	7.5	*****	11.	****	****	6.	75.
4	***	45.	14.0	5.64	0.310	28.1	211.	7.1	*****	26.	16.	****	14.	72.
5	***	21.	4.9	5.64	0.340	26.3	112.	7.5	*****	23.	****	0.01	14.	72.
6	***	16.	3.2	5.32	0.310	27.7	99.	7.7	*****	9.	****	****	12.	71.
7	***	28.	7.0	8.20	*****	41.1	184.	7.6	25.00	17.	****	****	12.	72.
8	***	18.	3.4	5.80	0.140	10.6	95.	7.5	*****	6.	****	****	27.	72.
9	***	18.	3.4	5.80	0.140	10.6	95.	7.5	*****	6.	****	****	12.	***
10	28.	9.	5.7	6.16	0.210	22.8	139.	7.4	15.00	10.	****	0.04	12.	74.
11	***	14.	4.4	5.64	0.290	33.2	151.	6.9	*****	48.	23.	****	10.	75.
12	***	17.	3.6	7.08	0.190	28.1	127.	7.1	10.00	11.	****	****	12.	74.
13	***	10.	2.0	7.08	0.230	24.5	83.	7.2	*****	10.	****	****	10.	74.
14	***	25.	7.3	9.28	0.240	47.3	134.	7.1	8.00	13.	****	****	12.	72.
15	***	****	****	****	*****	****	****	***	*****	****	****	0.01	17.	66.
16	***	***	****	****	*****	****	****	***	*****	****	****	****	27.	***
17	29.	28.	5.8	5.48	0.490	58.3	114.	7.4	8.00	10.	****	****	33.	***
18	***	33.	8.6	2.08	0.470	28.8	111.	7.2	*****	16.	5.	****	21.	72.
19	***	31.	8.0	1.24	0.390	37.1	125.	7.4	10.00	35.	****	****	11.	70.
20	***	18.	5.8	1.42	0.170	12.8	80.	7.6	*****	12.	****	****	9.	72.
21	***	23.	4.4	3.00	0.270	9.5	45.	7.3	12.50	14.	****	****	10.	72.
22	***	13.	2.8	1.98	0.220	5.4	55.	7.4	*****	7.	****	0.01	11.	74.
23	***	13.	2.8	1.98	0.220	5.4	55.	7.4	*****	7.	****	****	10.	***
24	31.	32.	6.5	1.54	0.270	9.6	85.	7.7	10.00	14.	****	****	12.	74.
25	***	40.	8.7	1.58	0.490	21.4	163.	7.5	*****	12.	9.	****	86.	70.
26	***	20.	6.0	1.50	0.680	50.9	149.	7.5	10.00	13.	****	****	16.	72.
27	***	20.	3.3	1.68	0.750	22.8	128.	7.0	12.50	18.	****	0.08	18.	70.
28	***	13.	2.8	1.46	0.380	13.6	70.	7.1	*****	12.	****	****	13.	71.
29	***	19.	7.4	0.76	0.360	26.2	128.	7.2	15.00	13.	****	****	14.	70.
30	***	12.	1.8	1.10	0.660	29.0	99.	7.0	*****	9.	****	0.00	16.	72.
31	***	13.	2.8	1.54	0.700	27.8	97.	7.0	10.00	8.	****	****	14.	71.
AVERAGE	28.	20.0	5.0	4.15	0.358	24.5	110.	7.3	12.00	14.1	13.2	0.02	16.2	72.

Table 40: WATER QUALITY DATA FEBRUARY, 1972 - PROCESS WATER API SEPARATOR EFFLUENT

DATE	FLOW G/D (MM)	OIL		NH$_3$-N mg/l	PHENOL mg/l	BOD mg/l	TOD mg/l	pH	TON (M)	TSS mg/l	VSS mg/l	PO4 mg/l	TURB. JTU
		I.R. mg/l	APHA mg/l										
1	35.				*****	****	****	***	****	*****	****	****	50.
2	****				*****	****	****	***	****	*****	****	****	59.
3	****				*****	****	****	***	****	*****	****	****	56.
4	****				*****	****	****	***	****	*****	****	****	51.
5	****				*****	****	****	***	****	*****	****	****	44.
6	****				*****	****	****	***	****	*****	****	****	57.
7	****				5.150	13.9	180.	7.5	****	13.	****	****	51.
8	****				5.150	13.9	180.	7.5	****	13.	****	****	53.
9	****				6.650	19.9	500.	7.6	****	69.	****	****	66.
10	34.				6.650	19.3	500.	7.5	****	69.	****	****	****
11	****				1.050	15.5	337.	***	****	28.	****	****	65.
12	****				1.050	15.5	337.	***	****	28.	****	****	74.
13	****				0.340	15.7	264.	7.4	****	29.	****	****	65.
14	****				0.340	15.7	264.	7.5	****	29.	****	****	69.
15	****				*****	****	****	***	****	*****	****	****	53.
16	****				*****	****	****	***	****	*****	****	****	60.
17	****				*****	****	****	***	****	*****	****	****	55.
18	33.				*****	****	****	***	****	*****	****	****	63.
19	****				*****	****	****	***	****	*****	****	****	74.
20	****				0.900	16.6	198.	7.8	****	167.	****	****	70.
21	****				0.900	16.6	198.	7.8	****	167.	****	****	66.
22	****				0.380	6.1	149.	7.4	****	22.	****	****	57.
23	****				0.380	6.1	149.	7.4	****	22.	****	****	****
24	****				1.840	56.9	384.	7.3	****	123.	****	****	58.
25	****				1.840	56.9	384.	7.3	****	123.	****	****	64.
26	****				1.940	60.4	576.	7.1	****	95.	****	****	81.
27	****				1.940	60.4	576.	7.1	****	95.	****	****	77.
28	33.				1.800	****	788.	7.1	****	74.	57.	****	67.
29	****				1.800	****	788.	7.1	****	74.	57.	****	52.
AVERAGE	33.				2.227	34.5	375.	7.4	0.00	68.8	57.0	0.00	61.3

APPENDIX C

Table 41: WATER QUALITY DATA FEBRUARY, 1972 - PROCESS WATER BIOPOND EFFLUENT

DATE	FLOW G/D (MM)	OIL I.R. mg/l	OIL APHA mg/l	NH_3-N mg/l	PHENOL mg/l	BOD mg/l	TOD mg/l	pH	TON (M)	TSS mg/l	VSS mg/l	PO_4 mg/l	TURB. JTU
1	35.	67.	11.3	1.38	0.590	34.2	283.	7.0	*****	14.	11.	****	103.
2	****	80.	39.0	2.90	0.610	118.3	440.	7.1	40.00	23.	****	****	85.
3	****	138.	55.2	3.86	1.090	115.1	492.	6.9	*****	34.	****	0.59	126.
4	****	78.	22.1	3.20	1.160	44.2	350.	7.0	30.00	29.	****	****	115.
5	****	115.	47.4	5.64	0.570	97.8	365.	7.1	25.00	39.	****	****	91.
6	****	37.	****	5.64	0.750	49.2	235.	7.5	*****	18.	****	****	81.
7	****	167.	49.7	1.54	0.660	95.3	354.	7.4	20.00	22.	****	****	74.
8	****	112.	39.0	5.48	0.490	97.3	359.	7.4	*****	26.	17.	****	69.
9	****	125.	59.0	4.04	0.780	117.0	407.	7.5	30.00	28.	****	****	81.
10	34.	177.	41.6	5.16	0.730	71.2	427.	7.3	30.00	37.	****	0.36	87.
11	****	102.	41.9	5.32	0.610	39.5	417.	7.2	*****	37.	****	****	115.
12	****	115.	49.5	3.64	0.500	62.0	365.	7.4	40.00	44.	****	****	96.
13	****	95.	33.1	3.44	0.410	66.4	382.	7.6	*****	38.	****	****	84.
14	****	87.	34.8	2.44	0.340	41.1	255.	7.5	17.50	37.	****	****	90.
15	****	119.	21.9	2.20	0.450	71.4	276.	7.4	*****	33.	16.	0.41	74.
16	****	94.	18.3	2.60	0.470	99.5	370.	7.3	40.00	38.	****	****	82.
17	****	137.	59.4	3.88	0.450	99.5	366.	7.7	*****	33.	****	****	103.
18	33.	66.	39.6	4.16	0.410	49.8	346.	8.1	90.00	29.	****	****	77.
19	****	100.	40.6	2.84	0.490	60.8	240.	7.8	*****	33.	****	****	66.
20	****	113.	58.1	2.92	0.380	78.1	327.	7.6	50.00	67.	****	0.47	61.
21	****	113.	58.1	2.92	0.380	78.1	327.	7.6	50.00	67.	****	****	70.
22	****	89.	36.2	2.08	0.450	76.6	450.	7.6	*****	43.	15.	****	62.
23	****	100.	43.2	3.00	0.380	18.5	430.	7.4	30.00	60.	****	****	62.
24	****	149.	72.0	3.24	0.380	17.8	406.	7.4	*****	62.	****	****	58.
25	****	91.	35.0	3.88	0.470	16.7	303.	7.4	50.00	45.	****	****	57.
26	****	288.	96.1	3.08	0.590	20.8	696.	7.7	*****	92.	****	0.37	112.
27	****	98.	32.4	3.88	0.290	23.1	254.	7.6	40.00	48.	****	****	118.
28	33.	222.	64.0	1.64	0.730	10.6	261.	7.8	*****	71.	****	****	80.
29	****	185.	86.8	2.60	0.380	23.9	216.	7.1	30.00	41.	26.	****	69.
AVERAGE	33.	119.3	45.5	3.39	0.551	61.8	358.	7.4	38.28	40.9	17.0	0.44	84.4

APPENDIX C

Table 42: WATER QUALITY DATA FEBRUARY, 1972 - PROCESS WATER TERTIARY TREATMENT EFFLUENT

DATE	FLOW G/D (MM)	OIL I.R. mg/l	OIL APHA mg/l	NH_3-N mg/l	PHENOL mg/l	BOD mg/l	TOD mg/l	pH	TON (M)	TSS mg/l	VSS mg/l	PO_4 mg/l	TURB. JTU	TEMP. °F.
1	35.	26.	3.7	1.38	0.590	32.8	150.	6.9	*****	10.	8.	****	28.	73
2	****	28.	12.6	2.74	0.920	81.4	201.	7.1	12.50	24.	****	****	22.	72
3	****	26.	11.0	3.70	0.880	39.9	179.	6.9	*****	12.	****	0.04	21.	72
4	****	32.	8.8	3.08	1.250	25.3	155.	6.9	10.00	20.	****	****	24.	70
5	****	31.	9.7	4.80	0.530	32.7	170.	7.1	12.50	14.	****	****	30.	69
6	****	38.	12.3	5.80	0.590	33.4	145.	7.4	*****	17.	****	****	28.	71
7	****	47.	12.4	1.78	0.450	35.0	152.	7.4	10.00	15.	****	****	37.	70
8	****	25.	10.2	6.00	0.550	18.6	98.	7.3	*****	8.	6.	****	23.	71
9	****	44.	13.2	4.64	0.880	37.2	144.	7.4	12.50	15.	****	****	23.	70
10	34.	50.	14.6	4.92	0.920	28.0	203.	7.4	15.00	17.	****	0.00	26.	70
11	****	41.	10.7	5.16	0.530	28.6	140.	7.2	*****	23.	****	****	44.	73
12	****	28.	9.2	3.56	0.390	15.0	95.	7.4	15.00	16.	****	****	26.	73
13	****	18.	3.0	3.24	0.390	21.1	97.	7.6	*****	12.	****	****	20.	72
14	****	18.	3.9	4.52	0.290	17.7	65.	7.4	8.00	8.	****	****	20.	72
15	****	54.	15.6	2.68	0.470	39.2	137.	7.3	*****	37.	16.	0.00	39.	73
16	****	50.	16.0	3.00	0.290	16.6	167.	7.4	6.00	17.	****	****	29.	73
17	****	28.	6.9	3.64	0.270	40.2	165.	7.8	*****	22.	****	****	26.	74
18	33.	18.	2.6	3.96	0.290	40.3	87.	8.2	9.00	14.	****	****	22.	75
19	****	20.	4.7	2.08	0.190	24.2	77.	7.9	*****	14.	****	****	21.	70
20	****	22.	5.0	2.60	0.290	21.3	77.	7.5	8.00	11.	****	0.02	18.	70
21	****	22.	5.0	2.60	0.290	21.3	77.	7.5	8.00	11.	****	****	16.	***
22	****	23.	5.3	2.08	0.250	20.6	74.	7.6	*****	8.	8.	****	14.	70
23	****	24.	5.8	3.00	0.310	23.8	66.	7.4	5.00	8.	****	****	14.	72
24	****	28.	4.4	3.44	0.230	25.0	98.	7.4	*****	22.	****	****	11.	73
25	****	14.	2.7	3.44	0.340	32.4	70.	7.4	7.00	9.	****	****	13.	74
26	****	71.	28.6	3.24	0.380	128.0	333.	7.2	*****	34.	****	****	28.	70
27	****	18.	4.6	3.76	0.380	44.1	89.	7.4	8.00	17.	****	****	34.	72
28	33.	20.	4.1	2.28	0.550	31.7	76.	7.7	*****	8.	****	****	12.	68
29	****	40.	****	****	*****	*****	****	***	*****	****	****	****	9.	76
AVERAGE	33.	31.2	8.8	3.46	0.488	34.1	128.	7.4	9.76	15.8	9.5	0.00	23.4	71

APPENDIX D

CENTRIFUGE STUDY TO DEWATER AIR FLOTATION SKIMMINGS

Although AFU skimmings are only about 10 per cent solids plus oil, water does not settle out readily. Pressure filtration will successfully dewater these skimmings, but the investment for equipment and expected operating costs were estimated to be prohibitive. Centrifugation appeared to be a better process from an investment viewpoint.

The horizontal scroll-type centrifuge, Sharples P-3000, was tested and found to be unsatisfactory for this service; performance was inconsistent. After subsequent discussions with the Sharples Company, a test program was designed to evaluate the basket-type centrifuge for this service. The differences between horizontal-bowl, conveyer centrifuges and basket centrifuges are discussed in the literature (1, 2, 3). The horizontal-bowl, conveyer centrifuge is fed sludge continuously and discharges clarified liquid and concentrated sludge. The basket centrifuge is an automated batch system where the feed enters the centrifuge basket and clarified liquid is discharged until the bowl is filled with concentrated sludge to capacity. Automatic timers then stop the feed and skim out the concentrated solids after which the cycle begins again. This basket-type of centrifuge was expected to concentrate the air flotation skimmings effectively because of their very fluid consistency.

Based on the favorable field performance of a 14-inch diameter, pilot-size, basket-type centrifuge, additional field tests were carried out with a fully automated 30-inch diameter, commercial-size centrifuge.

14-INCH DIAMETER PILOT BASKET CENTRIFUGE

The unit used for this pilot study was a Sharples/Fletcher Mark III unit 14-inch diameter times 6 inches deep with a variable speed hydraulic drive and a solid bowl. AFU skimmings and PERCOL-155 (anionic polymer) are fed into the centrifuge through a tee and pass out into the bottom of the centrifuge bowl. The coagulated solids are deposited on the sides of the bowl and build up until the capacity of the basket is reached. At this point, the feed is stopped and the solids are cut out by moving a tube device into the layer of sludge. The basket held 2.5 gallons concentrated sludge and was operated at 2,300 rpm to provide 1,300 G's for sludge concentration.

RESULTS OF PILOT CENTRIFUGE TESTS

The average daily AFU skimming and analyses during these tests are shown in Table 1. The overall average feed to the centrifuge for this two-week period consisted of 93.1 per cent water, 2.1 per cent solids, and 4.8 per cent oil. The results of this test period are shown in Table 2. The polymer added during this period varied from 60-320 mg/l (PERCOL-155). No appreciable difference could be determined in the length of runs, cake consistency, or overflow solids for different polymer dosages as long as coagulation of the AFU skimmings had been achieved. The polymer rate could not be controlled as closely as desired because of pumping problems associated with such small flows; however, most of the time, the AFU skimmings were coagulated with 100 mg/l of polymer. These skimmings were fed to the centrifuge directly from the sludge pit without heating or the addition of any other chemicals. Most of the tests were run at 1.3-gpm feed rate to the centrifuge because of pump limitations, although it appeared that the optimum feed rate would have been higher. During two different periods, a 2.7-gpm centrifuge feed rate was achieved and produced good results; however, this was a period when skimming characteristics allowed unusually good coagulation of the solids and oil.

These tests indicated that a basket centrifuge could produce almost 90 per cent solids recovery with a solids content in the clarified liquid of less than 3,000 mg/l and a concentrated sludge or cake of 76 per cent water. This produced a cake of 3,300 BTU/lb. (calculated heat value) that could be pumped. These results show that 3.4 pounds of AFU skimmings could be concentrated to one pound of cake, when the skimmings contain 93 per cent water.

Table 3 shows that the oil-to-solids ratio was about three in the AFU skimmings during these tests. The oil-to-solids ratio in the cake was less than that in the skimmings showing that some oil is released from the solids and passes out in the clarified liquid.

These results were encouraging enough to consider this type of centrifuge on a larger scale, so the next series of tests were conducted on a full-size centrifuge.

APPENDIX D

Table 1: DAILY AFU SKIMMINGS DATA USED FOR FEED TO 14-INCH CENTRIFUGE

Day	AFU Skimmings, %		
	Solids	Oil	Water
1	3.1	4.8	92.1
6	3.8	3.0	93.2
13	2.2	8.4	89.4
17	2.8	6.0	91.2
18	1.2	3.2	95.6
19	0.9	4.4	94.7
20	1.8	4.0	94.2
21	2.6	6.7	90.7
24	2.8	6.2	91.0
25	1.6	4.0	94.4
27	1.4	2.4	96.2
28	1.2	4.3	94.5
Average Values	2.1	4.8	93.1

APPENDIX D

Table 2: AVERAGE OPERATING DATA FOR PILOT BASKET CENTRIFUGE

Ave. Feed Rate To Cent., gpm	Time for Solids Break-Through, min.	Oil(1) Recovery, %	Solids Recovery(2), %	Solids In Overflow, mg/l	AFU Skimmings				Cake			
					Solids, %	Oil, %	Water, %	Heat, BTU/lb.	Solids, %	Oil, %	Water, %	Calculated Heat Value(3), BTU/lb.
0.5	14	73	99	500	2.2	8.4	89.4	1,620	4.6	13.0	82.4	2,570
1.0	5.5	71	88	4,430	2.3	7.9	89.8	1,540	5.2	14.4	80.4	2,850
1.3	7.2	69	89	2,740	1.9	4.9	93.2	980	8.0	16.0	76.0	3,320
2.0	2.6	33	44	13,128	2.0	6.1	91.9	1,200	6.3	14.5	79.2	2,930
2.5	2.9	53	83	3,700	1.7	5.6	92.7	1,090	7.0	14.8	78.2	3,010

(1) Oil Recovery $= \frac{\text{pounds Oil in Cake}}{\text{pounds Oil in Skimmings}} = \frac{\text{Oil-to-Solids ratio in Cake}}{\text{Oil-to-Solids ratio in Skimmings}} \times$ Solids Recovery

(2) Solids Recovery $= R = \frac{Ck\ (Cf-Cc)}{Cf\ (Ck-Cc)} \times 100$

See "Estimation of Sludge Centrifuge Performance"
Journal of Sanitary Engineering Division,
ASCE, Vol. 96, No. SA-3 (June, 1970)

(3) Based on 5,000 BTU/lb. of solids and 18,000 BTU/lb. of oil and soxhlet analysis of cake.

APPENDIX D

Table 3: OIL-TO-SOLIDS RATIOS FOR PILOT BASKET CENTRIFUGE

Feed Rate To Cent.	Oil-to-Solids Ratio	
	AFU Skim	Cake
0.5 gpm	3.8	2.8
1.0	3.4	2.8
1.3	2.8	2.0
2.0	3.0	2.3
2.5	2.7	2.1

Table 4: OVERFLOW SOLIDS REDUCTION BY REMOVAL OF CAKE DIVERSION VALVE FOR CONTINUOUS CENTRIFUGE OPERATION

	Diversion Valve in Use			No Diversion Valve		
Run	1 (mg/l)	2 (mg/l)	3 (mg/l)	1 (mg/l)	2 (mg/l)	3 (mg/l)
Composite Overflow Solids	14,200	4,350	6,950	2,040	1,770	1,570
Clean* Overflow Solids	6,130	2,860	4,210	1,580	1,520	1,360

*Clean samples taken near the middle of the feeding cycle. This sample usually provides the cleanest possible overflow.

30-INCH DIAMETER COMMERCIAL BASKET CENTRIFUGE

The unit used for these tests was a Sharples/Fletcher Whirl-O-Matic centrifuge 30-inch diameter times 15 inches deep and was operated at a fixed speed to obtain 1,300 G's, identical to the pilot centrifuge. The basket had a sludge capacity of 30 gallons. Polymer (PERCOL-155) was fed into the basket near the bottom through a tube passing down from the top to the unit. This unit could be operated either manually or automatically with a continuously controlled time cycle. The flow diagram of this system is shown in Figure 1. This is the smallest commercial basket centrifuge that Sharples Company manufactures.

SAMPLING PROCEDURES FOR 30-INCH CENTRIFUGE TESTS

Inlet samples to the centrifuge were taken for each batch run; samples of the AFU feed material were taken at the end of the cake-removal cycle during continuous centrifuge operation. The total cake was caught in a 55-gallon barrel and thoroughly mixed to obtain a representative composite cake sample. Composite overflow samples were obtained in two ways. Firstly, quart samples were taken every 30 or 60 seconds (depending on the length of the feed cycle) and mixed in a five-gallon pail to obtain a composite overflow. Secondly, a small, continuous slip stream of the overflow was allowed to flow into a five-gallon bucket during the centrifuge run to produce a composite overflow sample. An overflow grab sample was also taken along with each composite sample about halfway through the feeding cycle. These grab samples confirmed that excessive solids and oil were not discharged at the start of the feeding cycle or the cake-cutting cycle. For several runs, overflow samples were taken every minute and analyzed separately to determine if there were changes in the overflow during any part of the cycle.

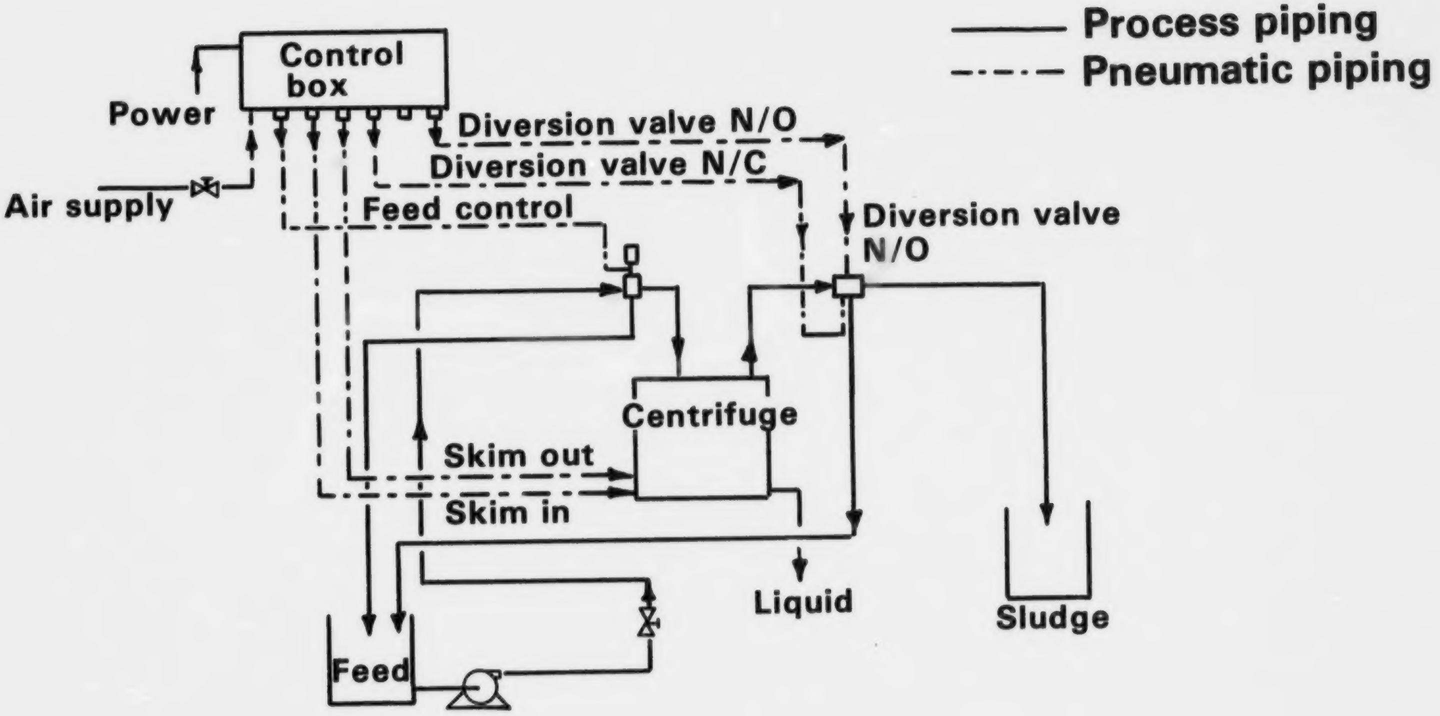
Cake and AFU skimming samples were analyzed for solids, oil, and water using the modified carbon tetrachloride soxhlet extraction method. Solids in the overflow were determined by filtration, with a solvent wash to remove the oil from the solids.

PROBLEM WITH WATER-CAKE DIVERSION VALVE

During initial testing of the automated centrifuge, an unexpected problem was incurred with excessive carry-over of solids into the

Appendix D - Figure 1

30-inch basket centrifuge


Process piping
Pneumatic piping
Control box
Power
Air supply
Diversion valve N/O
Diversion valve N/C
Feed control
Diversion valve N/O
Centrifuge
Skim out
Skim in
Liquid
Sludge
Feed

overflow during the feed cycle. At first, it was thought that this problem was due to too long a feed cycle. Considerable effort was spent in an attempt to solve this problem, since it greatly reduced the effectiveness and efficiency of the centrifuge.

Figure 2 shows the effect of not washing the centrifuge bowl prior to a batch run. Both runs were made at 11-1/2 gpm feed rate to the centrifuge. This showed that a large amount of solids (and oil) remained in the outer bowl and overflow lines from the previous run. The run where the bowl had not previously been washed produced a very much higher overflow solids which could be due to at least two things:

1. Excessively long feeding cycle past breakthrough of the previous run.

2. Dirtying of the centrifuge outer bowl during cutting the cake.

Breakthrough occurred for both these runs slightly after five minutes.

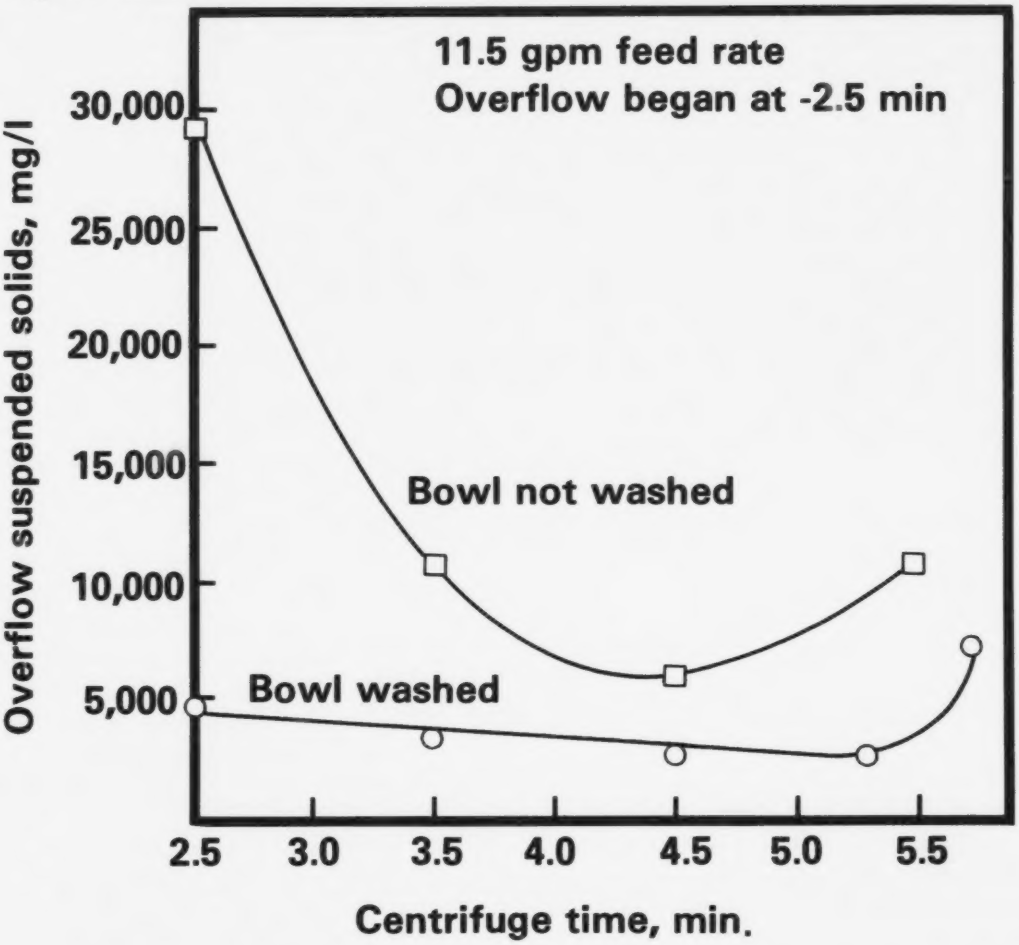
Figure 3 shows the effect of varying the feeding cycle during continuous operation of the centrifuge. The four-minute cycle produced a much cleaner overflow than did the five-minute cycle. Breakthrough during these tests was 4-3/4 minutes. Thus excessively long feeding cycle time did produce a dirty overflow. However, this was not the entire answer, since even the four-minute feeding cycle produced a very high overflow solids level and breakthrough was never reached during this type of operation.

Since the cake-cutting rate had been arbitrarily set at 1-1/2 minutes and had not been adjusted up to this time, slower cake-cutting rates were tried but did not reduce the overflow solids level. Leaving the top door open on the centrifuge, it was possible to watch, from a distance, the cake splatter against the outer bowl during the cake-cutting cycle, for a wide range of cake removal rates.

As shown in Figure 1, a diversion valve is used in this centrifuge to prevent water from passing out into the concentrated sludge pit. When this centrifuge is used to concentrate other types of sludges such as activated sludge, a water layer will exist on top of the cake layer. This is usually diverted to the feed storage in order to keep the cake as concentrated as possible. Concentration of the air flotation skimmings did not leave any substantial water layer. When breakthrough (solids and oil passing into the overflow stream)

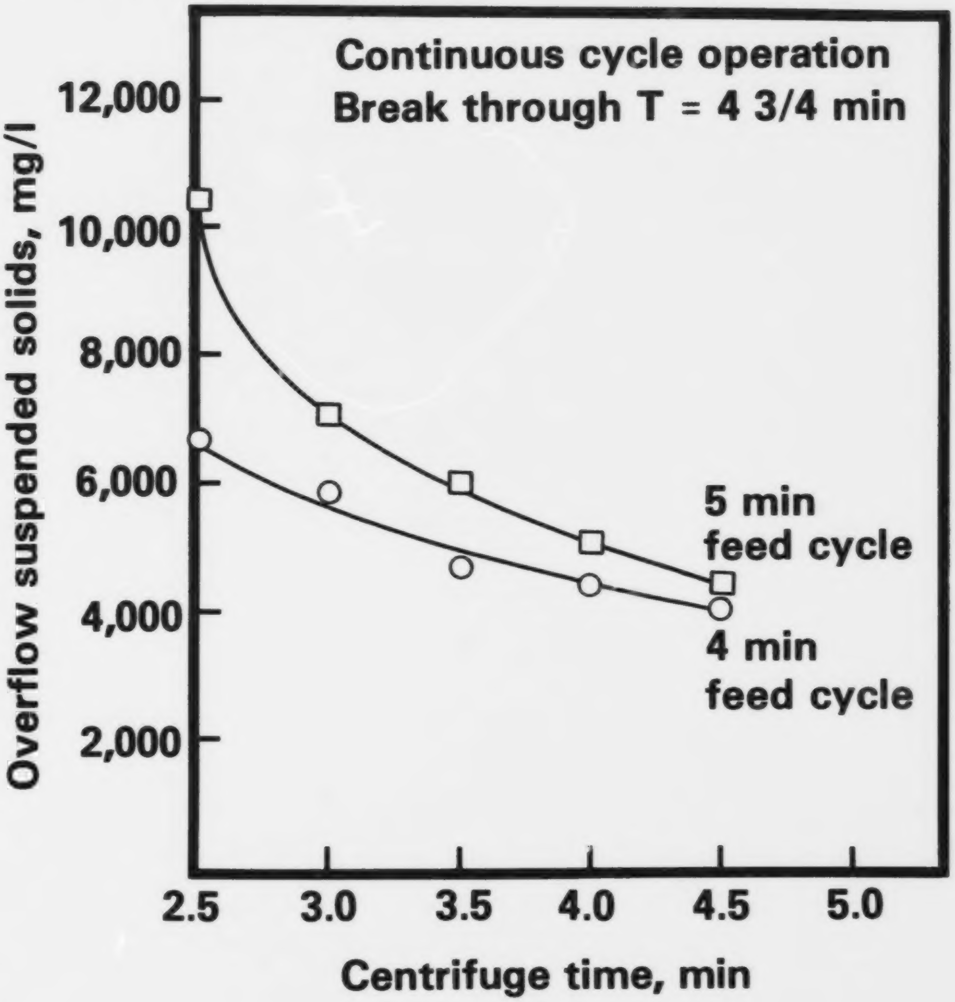
Appendix D - Figure 2

Effect of washing bowl for batch operation



Appendix D - Figure 3

Effect of feed cycle time on overflow solids



occurred during the centrifuging of AFU skimmings, the basket was essentially full of concentrated solids and oil. Therefore, the diversion valve wasn't actually needed for this sludge. The cake diversion valve caused excessive back pressure in the cake-removal tube and did not allow the cake to be removed rapidly enough. Thus splattering of the cake resulted from a full skimming tube. To circumvent the problem, the cake diversion valve was removed and a larger hose was used to remove the cake. The results of these changes were dramatic, as shown in Table 4. Three different runs with the cake diversion valve in place are compared with three runs without the diversion valve. When the diversion valve was removed, the "clean" overflow samples (samples taken near the middle of the feeding cycle) were nearly the same as the composite samples. Excellent centrifuge operation continued thoughout the testing, and overflow solids concentration remained very low.

RESULTS OF COMMERCIAL CENTRIFUGE TESTS

One run was made using four parts of AFU skimmings thoroughly mixed with one part of API separator sludge to determine if this type of centrifuge could concentrate these sludges when mixed together. The overflow was clean during this run; however, the cake could not be removed with the skimming device provided. The cake was packed in against the bowl so hard it was very difficult to remove by hand. No further runs were made using API separator sludges. All data presented were obtained using fresh AFU skimmings for feed material.

The average daily AFU skimming data are shown in Table 5 for the test period of evaluating the 30-inch diameter centrifuge. The average AFU skimmings during these tests contained 87.5 per cent water, 3.4 per cent solids, and 9.1 per cent oil. Thus, the analyses of these skimmings indicated that they contained nearly twice as much oil and substantially less water than the skimmings used for evaluating the 14-inch pilot centrifuge.

The average data from these centrifuge tests are shown in Table 6. These data are averaged for each of four different feeding rates to the centrifuge. The continuous feeding rate represents the actual rate of removal or concentration of AFU skimmings on a 24-hour basis including the cake removal cycle time. The solids recovery values were determined by the equation $R = Ck\ (Cf-Cc)/Cf\ (Ck-Cc) \times 100$, where Cf, Ck, and Cc are the

APPENDIX D

Table 5: AVERAGE DAILY AFU SKIMMINGS DATA USED FOR FEED TO 30-INCH DIAMETER CENTRIFUGE

	AFU Skimmings, %		
Day	Solids	Oil	Water
1	2.6	7.4	90.0
2	3.7	7.1	89.2
4	3.7	8.0	88.3
5	4.0	12.8	83.2
7	3.5	7.2	89.3
8	3.0	10.4	86.6
12	3.6	6.8	89.6
13	3.3	9.6	87.1
14	4.2	8.2	87.6
15	1.9	10.3	87.8
16	4.1	11.9	84.0
18	3.8	8.4	87.8
19	3.4	11.2	85.4
20	3.6	8.9	87.5
Average Values	3.4	9.1	87.5

APPENDIX D

Table 6: AVERAGE OPERATING DATA FOR THE 30-INCH DIAMETER BASKET CENTRIFUGE

Feed Rate To Cent.	Cont(1) Feed Rate	Time for Solids Break-Through	Oil Recovery(2)	Solids(3) Recovery	Solids In Overflow (4)	AFU Skimmings				Cake			
						Solids	Oil	Water	Heat Val.	Solids	Oil	Water	Heat Val. (6)
gpm	gpm	min.	%	%	mg/l	%	%	%	BTU/lb.	%	%	%	BTU/lb.
8	6.9	6.3	69	90	4,780(5)	2.8	7.9	89.3	1,460	6.5	14.1	79.4	2,860
11.5	9.9	6.2	88	95	1,700	3.6	8.1	88.3	1,640	8.9	18.7	72.4	3,810
14	11.2	4.0	84	94	2,440	3.6	8.1	88.3	1,640	7.0	14.1	78.9	2,890
18	13.4	2.9	70	95	3,025	3.4	10.0	86.6	1,970	6.8	14.8	78.4	3,000

(1) Continuous Feed Rate = $\dfrac{\text{Feed rate to centrifuge x feed cycle time}}{\text{Feed cycle time + 1-min. cake-removal cycle time}}$

(2) Oil Recovery = $\dfrac{\text{pounds oil in cake}}{\text{pounds oil in skimmings}} = \dfrac{\text{oil-to-solids ratio in cake}}{\text{oil-to-solids ratio in skimmings}}$ x Solids Recovery

(3) Solids Recovery: See "Estimation of Sludge Centrifuge Performance," Journal of Sanitary Engineering Division, ASCE, Vol. 96, No. SA-3 (June, 1970).

(4) Overflow solids are composite samples with the cake diversion valve not in use for all cases with the exception of (5).

(5) These overflow samples are composite with the diversion valve in place.

(6) Calculated values based on 5,000 BTU/lb. of solids and 18,000 BTU/lb. of oil and soxhlet analysis of cake.

feed, cake, and concentrate (overflow) solids concentration in per cent solids.(4) The oil recovery values were determined by the equation Roil = Ratio Oil: SS in Cake/Ratio Oil: SS in Skimmings x R. Both of these equations are mathematically identical to:

$$R = \frac{\text{\# solids (or oil) in cake}}{\text{\# solids (or oil) in feed}} \times 100$$

Heating values for the AFU skimmings and cake were calculated using values of 5,000 BTU/lb for solids and 18,000 BTU/lb for oil.

The data shown for 8-gpm feed rate to the centrifuge were obtained during the initial period of testing with the cake diversion valve in place. The 11-1/2 and 14-gpm feed rates were used for most of the test runs and thus represent two-thirds of the total data. The 18-gpm feed rate was only used during ideal centrifuging conditions when the AFU skimmings would flocculate into especially large particles.

The average oil-to-solids ratios of the AFU skimmings and the centrifuge cake are shown for the four feeding rates used in Table 7. The oil-to-solids ratios were again higher for the AFU skimmings than in the cake samples; thus more oil than solids passed out with the overflow. The oil concentrations in the overflows were not determined, because there was no standard analytical procedure for extracting the oil from the coagulated solids.

In all cases, the polymer requirements for centrifuge operation were predicted using jar test results. The minimum polymer requirements for good centrifuge operations are compared with the minimum amount of polymer needed for coagulation of the skimmings in beakers (Jar test) in Table 8. Often, less polymer could be used than expected. After coagulation was achieved, no improved benefits were found in the centrifuge operation by using more polymer. Polymer concentrations two or three times greater than required for good flocculation and coagulation produced no detectable harmful effects to the centrifuge operation.

Since the purpose of this work was to determine if the centrifuge could effectively dewater the skimmings, no attempt was made to operate the centrifuge to obtain less than optimum solids recovery. As shown in the probability plot of the centrifuge data (Figure 4), the centrifuge provided 92.7 per cent greater solids recovery for

APPENDIX D

Table 7: AVERAGE OIL-TO-SOLIDS RATIOS FOR 30-INCH DIAMETER CENTRIFUGE TESTS

Feed Rate To Cent.	Oil-to-Solids Ratio	
	AFU Skim	Cake
8 gpm	2.8	2.2
11.5	2.3	2.2
14	2.3	2.0
18	2.9	2.2

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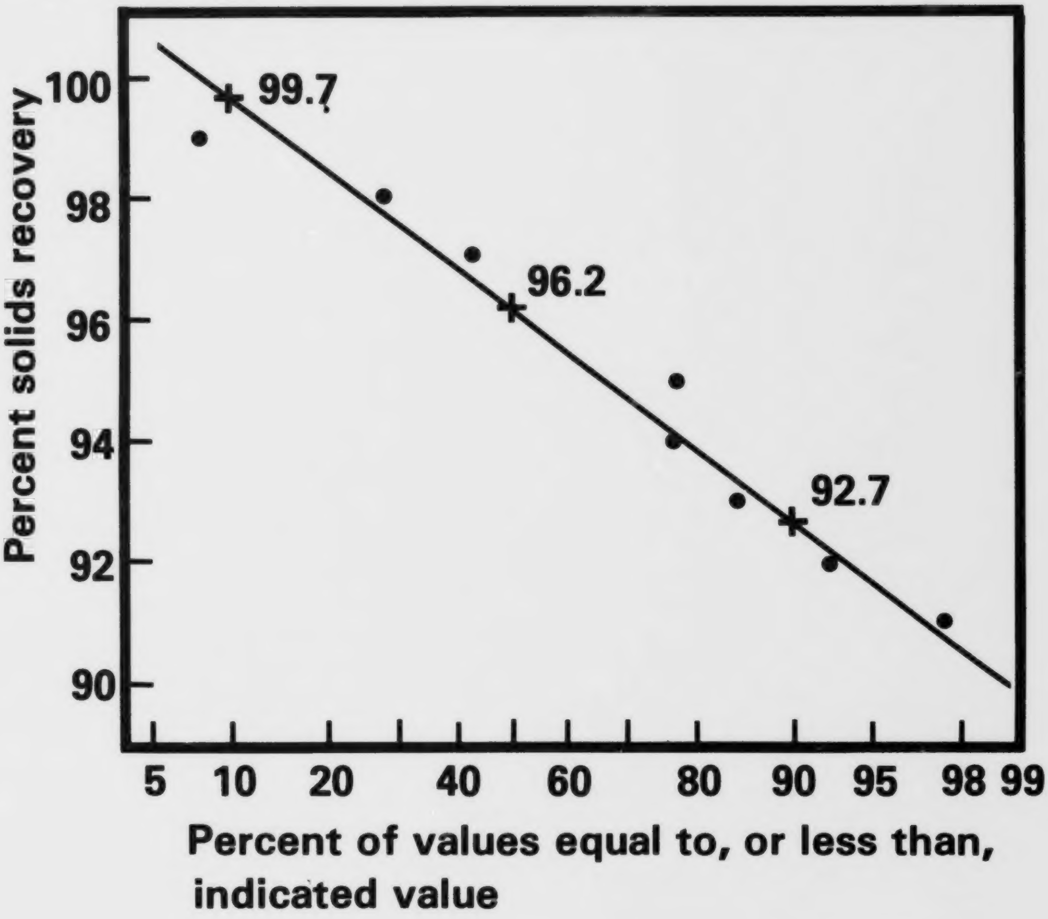
Table 8: COMPARISON OF POLYMER RATES USED WITH JAR TEST RESULTS

	Percol-155	
Day	Min. Used for Cent.	Jar* Test
0	94 mg/l	----
1	195	----
2	120	----
4	65	67 mg/l
5	85	----
7	85	----
8	85	----
12	54	75
13	84	----
14	85	75
15	94	100
16	78	75
18	84	75
19	84	100
20	110	125
21	----	125
22	----	100
Average Values	$\overline{93}$ mg/l	$\overline{92}$ mg/l

*JAR TEST--Flocculation-coagulation tests conducted in several jars at different concentrations of polymer to determine the required polymer dosage. The jar test value was the lowest concentration of polymer to produce good coagulation

Appendix D - Figure 4

Percent solids recovery for 30-inch centrifuge



90 per cent of the time; the average (50 per cent value) solids recovery for all the centrifuge runs was 96.2 per cent. Therefore, it was not possible to plot curves for some of the parameters usually of interest in centrifuge studies such as solids recovery versus solids in feed, solids recovery versus water in feed, etc.

SCALE UP--FROM 30-INCH TO 48-INCH CENTRIFUGE

Although scale up would be done by the centrifuge manufacturer, data from this study can be used to predict scale up factors. Since the centrifuge accumulates oil and solids and rejects water, a reasonable scale up can be obtained by comparing the solids and oil feed rates and the solids and oil holding capacities regardless of water content. Table 9 shows the performance of the 30-inch centrifuge in comparison with the predicted performance of the largest commercial size, 48-inch centrifuge. The continuous feed rates shown in Table 9 are for the 11.5 gpm rate, assuming a feed time of 6.2 minutes and a cake-removal time of 30 seconds which was specified by the manufacturer. Several runs were made at 30 seconds and confirmed that this was realistic; but due to the fact that the small cake discharge hose whipped badly at the higher cake discharge rate, most of the runs used a 60-second cake removal.

APPLICATION

The effect of water removal from any sludge is shown in Table 10, assuming all the solids and oil are removed in the concentrated sludge. As can be seen, if a sludge contains 95 per cent water and is concentrated to a cake containing 75 per cent water, the actual volume reduction is four-fifths. Thus, five pounds of skimmings would produce one pound of cake for the 30-inch centrifuge and five pounds of skimmings per pound of cake for the 14-inch centrifuge. The skimmings fed to the 30-inch centrifuge contained less water, however, than those fed to the 14-inch centrifuge, but their cake contents were nearly the same. Hence, the 14-inch centrifuge produced a greater volume reduction than the 30-inch centrifuge. This would be especially important for periods when very wet skimmings are produced from the air flotation facilities; one can expect, when more water is present in the centrifuge feed, more water will be removed, and the cake will have a relatively uniform consistency. A statistical evaluation of the air flotation skimmings is shown in Table 11 and indicates that widely varying water contents can be expected from the air flotation unit skimmings.

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Table 9: SCALE UP 30-INCH TO 48-INCH CENTRIFUGE

	30-Inch	48-Inch
Feed Rate--gpm	11.5	(45.7)
Continuous Feed Rate(1)--gpm	10.6	(42.3)
Solids + Oil Feed(2)--lb./min.	10.3	(41.2)
Cake-Holding Capacity--gal.	30	120
$\frac{\text{Solids + Oil Feed}}{\text{Cake-Holding Capacity}}$	0.343	(0.343)

NOTE: Numbers in parenthesis are predicted scale up for 48-inch centrifuge.

(1) Continuous Feed Rate = $\frac{\text{Feed Rate x Feed Time}}{\text{Feed Time + Cake Removal Time}}$

(2) Solids + Oil Feed = Continuous Feed Rate x 8.33 x $\frac{\text{\% Solids + \% Oil}}{100}$

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Table 10: EFFECTS OF WATER REMOVAL ON SLUDGE VOLUME REDUCTIONS

Sludge Characteristics			
% Water	lbs. Water	lbs. Solids and Oil	lbs. Sludge
95%	95 lbs.	5 lbs.	100 lbs.
90	45	5	50
85	28	5	33
80	20	5	25
75	15	5	20
70	12	5	17

Table 11: STATISTICAL EVALUATION OF ALL AIR FLOTATION SKIMMINGS

Component (% of Total Skimmings)	Mean Value	Range for 68% (+ 1Θ)	Range for 95% (+ 2Θ)
Water	89.7%	91.6% - 85.8%	97.5% - 81.9%
Solids	3.0	4.2 - 1.8	5.5 - 0.5
Oil	7.3	10.4 - 4.2	13.5 - 1.1

CONCLUSIONS

The water content of the AFU skimmings can be markedly reduced in a basket-type centrifuge with the aid of a small amount of coagulating polymer. The volume reduction can result in significant dollar savings whether the skimmings are being disposed of by way of incineration, land fill, or land-spreading operations. The following conclusions were made:

1. The volume reduction effected by the centrifuge varies inversely with the water content of the skimmings. During the test period, volume reductions ranged from 50 per cent to 80 per cent.

2. Solids recovery, oil recovery, and cake water content can be maintained relatively constant by adjusting the centrifuge time cycle (feed time versus cake-removal time) to compensate for changes in water content of the skimmings. During the test period, averages achieved were: (1) solids recovery, 95 per cent; (2) oil recovery, 88 per cent; and (3) cake water content, 75 per cent.

3. Cake-heating value can be maintained relatively constant by controlling the water content of the cake, but some variations can be expected due to changes in the ratio of oil-to-solids in the skimmings. During the test period, calculated cake-heating values of over 3,000 BTU/lb. were achieved.

REFERENCES:

(1) Manual on Disposal of Refinery Wastes, Vol. VI by API (1963).

(2) "Centrifugation Application" Filtration Engineering, (Sept., 1969).

(3) "Centrifuges in Water and Waste Treatment" Chemical Engineering Progress, (Nov., 1969).

(4) "Estimation of Sludge Centrifuge Performance," J. San. Eng. Div., ASCE, Vol. 96, SA-3, (June, 1970).

APPENDIX E

LABORATORY TEST METHODS

I.R. Oil	Manual on Disposal of Refinery Wastes, API Test No. 733-58 Calibration is done by measuring the absorbance of typical recovered oil.
APHA Oil	Standard Methods,* 12th Edition, p. 211.
Ammonia-Nitrogen	"FWPCA Methods for Chemical Analysis of Water and Wastes," Nov., 1969, p. 127.
Phenolics	Standard Methods,* 12th Edition, p. 516, Method B.
BODS	"Standard Methods,"* 12th Edition, p. 415 D.O. determined by Weston & Stack Model 300 D.O. analyzer.
COD	"A Rapid COD Test," J. S. Jeris, Water and Wastes Engineering, May, 1967.
TOD	Model 225 Total Oxygen Demand Analyzer by Ionics, Incorporated, measures nitrogen and sulfur as well as carbon.
pH	Sergeant-Welch Model LS pH meter.
TON	Standard Methods,* 12th Edition, p. 304. Tests are made in room with carbon filters by especially sensitive technician, whose results are higher than other laboratories by a factor of 10 to 20.
Total Susp. Solids	Standard Methods,* 12th Edition, p. 425.
Volatile Susp. Solids	Standard Methods,* 12th Edition, p. 425.
Phosphate	Standard Methods,* 12th Edition, p. 234.

Turbidity	Hach Model 1860 Turbidimeter. Turbidity should be obtained immediately on a sample; thus, we are cognizant that 24-hour composite samples yield imperfect turbidity data.
Sulfonates	Standard Methods,* 12th Edition, p. 297.

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*Full Title: Standard Methods for Examination of Water and Waste Water. American Public Health Association, Incorporated.

APPENDIX E

SOXHLET EXTRACTION METHOD, INFRARED SPECTROMETRIC MODIFICATION

1. General Discussion

1.1 Principle: The sample is extracted in a Soxhlet apparatus using carbon tetrachloride. Because the specific gravity of CCl_4 is greater than water, the standard Soxhlet water trap is replaced by an Ace Glass Company No. 7780. Sample size is limited to 5 grams.

The oil content of the CCl_4 is then determined by the infrared spectrometric procedure, and solids are measured by weight. Water is determined by difference.

2. Apparatus

2.1 Soxhlet Extraction Apparatus.
2.2 Moisture Trap, Ace Glass No. 7780.
2.3 Apparatus for infrared spectrometric oil analysis.

3. Reagents

3.1 Spectrometric grade carbon tetrachloride.

4. Procedure

4.1 Dry and weigh an extraction thimble.

4.2 Insert approximately 5 grams of sample into the thimble. If the sample is relatively dry, this can be done directly. If the sample is wet, pour the sample into a beaker, weigh, and then pour the sample from the beaker into the thimble and reweigh the beaker.

4.3 Put about 190 cc of CCl_4 in the Soxhlet apparatus.

4. (Cont'd.)

4.4 Put the thimble in the Soxhlet apparatus.

4.5 Using an electric heating mantle, bring the CCl_4 to a boil and reflux until the extract is clear. Usually, four hours is sufficient reflux time.

4.6 Shut off heating apparatus, and allow equipment to cool.

4.7 Pour extract into a graduated cylinder, and dilute with fresh CCl_4 to a 200 cc. Analyze the extract for oil content using the spectrometric procedure.

4.8 Dry and weigh the extraction thimble plus solids.

Precision and Accuracy

Experience indicates precision is within ± 10 per cent. Other published data indicates the accuracy of the spectrometric procedure is within ± 20 per cent.

APPENDIX F

JAR TEST PROCEDURE (1)

For efficient clarification of refinery waste waters, it is advisable to determine the optimum conditions for coagulation, flocculation, and sedimentation. This may be done by use of the jar test procedure.

Jar tests usually are run as a series. Laboratory electrically driven mixers or stirrers are available which will mix six samples at a time, the speed of the paddles being regulated by a rheostat. Convenient sample sizes are 1,000 ml in 1,500- or 2,000-ml beakers. Other sample sizes may be used if desired.

Each series should be run so that only one factor is varied at a time. Usually, the first factor to be considered is the effect of pH on coagulation. A series of samples can be run in which the acid or alkali dosage is varied so that each sample has a different pH. The amount and order of addition of all other chemicals and aids, the duration of mixing periods, the temperature, and any other factors should remain constant.

After a coagulant and the optimum pH range are tentatively selected, the effect of varying the coagulant dosage can be studied, other factors remaining constant.

FLASH MIXING

The samples should be flash-mixed by vigorous stirring while chemicals are added to the samples rather rapidly. Approximately the same rate of chemical addition and the same mixing time should be used in all samples.

The flash-mix period should be not less than 30 seconds and may be as long as 4 minutes. The flash-mixing operation should be observed closely. If, after the floc is formed, it is broken up by prolonged mixing, the flash-mixing time should be reduced.

The order of addition of the acid or alkali, coagulant, and coagulant aid should be investigated. The speed of floc formation and character of the floc may change materially with the order of chemical addition. This is particularly true of coagulant aids, especially activated silica.

FLOCCULATION

A flocculation period, in which only enough mixing is required to keep the water circulating and the floc particles in intimate contact with the water, follows the flash-mixing period. Too little mixing may contribute to incomplete floc formation and unsatisfactory clarification and color reduction. Too vigorous mixing may cause floc breakup and poorly clarified water.

Complete floc formation may take place in a time period ranging between 5 minutes and 20 minutes. During the flocculation period, the samples should be observed and the rate of floc formation and the floc particle size recorded. The color and clarity of the water between the floc particles may also be recorded. The samples should be compared for flocculating differences that should be listed as best, second best, and so on, in the series.

As an arbitrary criterion, the size of the floc particles may be described as:

a. Pinpoint--extremely fine but visible.
b. Fine--average particle size, 1/64 inch.
c. Small--average particle size, 1/32 inch.
d. Fair--average particle size, 1/32 inch to 3/64 inch.
e. Good--average particle size, 3/64 inch to 3/32 inch.
f. Large--average particle size, 1/4 inch and larger.

SETTLING

After flocculation, the floc should be allowed to settle quiescently. Settling rate and time required for complete settling of the floc in each sample should be observed and recorded.

Generally, the larger the floc particles, the more rapid the settling rate. The size of the floc and its settling rate are criteria of chemical flocculation effectiveness. The most important criterion is the quality of the treated water after settling. Effectiveness of chemical coagulation and sedimentation on water quality should be determined by laboratory tests.

CLARIFIED WATER QUALITY

The required quality of treated water will determine the tests to be made. Usually, pH, color, turbidity, and oil determinations are desired.

These and other analyses which may be of interest can be determined by the methods given in the latest edition of Standard Methods for the Examination of Water, Sewage, and Industrial Wastes published by the American Public Health Association, or in the volume on Sampling and Analysis of Waste Water of this manual.

CHEMICAL COAGULANTS AND COAGULANT AIDS

The more common chemical coagulants used are filter alum, ferric or ferrous sulfate, sodium aluminate, and ferric chloride. Among the coagulant aids are lime, soda ash, activated silica, bentonite or other clays, and a number of proprietary compounds that are commercially available.

Solutions or suspensions of the coagulants and aids are prepared for dosing the samples. The materials used should be of the same quality or grade as those to be used in the plant operation. Solutions should be prepared in concentrations that are convenient to be used with the particular sample size chosen. For example, with a solution of 1 g of substance in 1 liter of water, 1 ml of this solution in a liter of sample will be equivalent to a dosage of 1 mg per liter.

The solution strength should be such that when the required dosage is added to the sample, no appreciable change in total volume of the sample results. A Mohr pipet, graduated in 0.1-ml units, will be found convenient for measuring the solutions.

Solutions of some chemicals deteriorate rapidly. Care must be taken to ensure that all solutions are of the proper strength when used.

It may be desirable to investigate the effect of sludge recirculation on floc formation. This can be accomplished by treating enough water, under optimum treating conditions, to yield and recover sludge approximately 5 to 10 per cent of the volume of the sample to be treated. This settled sludge should be added to the sample, followed by the treatment chemicals, and the results observed. An identical sample should be run for control, using the same treatment but without the sludge.

EVALUATION OF RESULTS

Jar test will indicate the optimum treating conditions for a given clarified water quality. Jar tests indicate:

a. Optimum pH value for efficient coagulation with different coagulants.

b. Optimum coagulant dosages for effective flocculation.

c. Effectiveness of the various coagulant aids.

d. Most effective order of chemical addition.

e. Correct mixing times.

f. Floc settling characteristics.

g. Quantity of sludge requiring disposal.

h. Quality of clarified water to be expected from a particular treatment.

From these data, the size of equipment required and plant costs can be estimated.

As the quality of waste water to a clarifier varies, chemical dosages must also vary for efficient clarification. Jar tests will guide operators in determining chemical dosages and adjustments to maintain effluent quality.

REFERENCES:

(1) API Manual on Disposal of Refinery Wastes, Volume on Liquid Wastes, Chapter 9--Appendix 1.